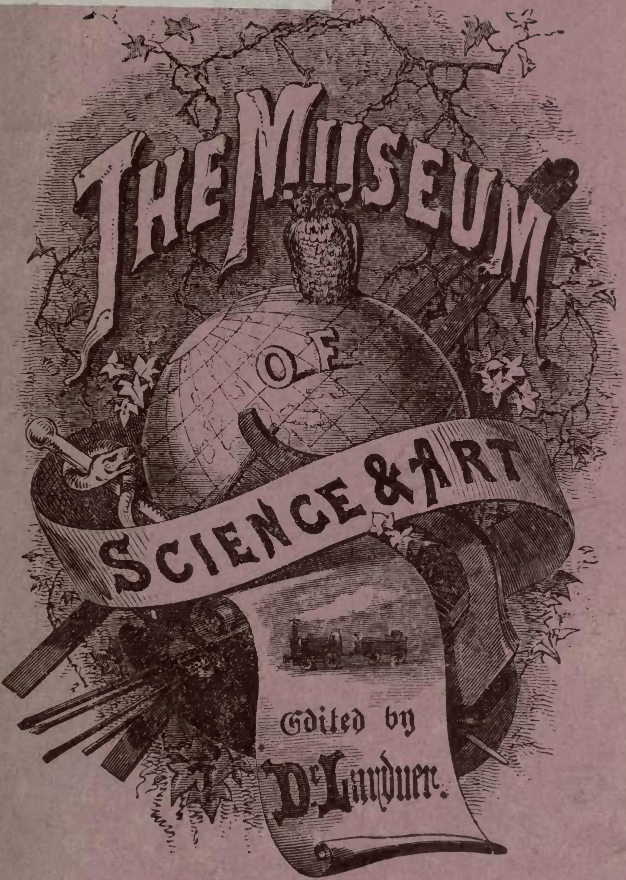

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UPPER GOWER STREET & IVY LANE.

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THE CRUST OF THE EARTH,

OR, FIRST NOTIONS OF GEOLOGY.

THE STEREOSCOPE.

COMETS.

ERRATA.

In Crust of the Earth, page 59, lines 1 to 19 inclusive, *for* "species" *read* "genera" *or* "genus" everywhere without exception.

Fig. 2.

THE PRINTING PRESS.

CHAPTER I.

1. The improvement of the art not promoted by men of letters and science.—2. General signification of printing.—3. Printing by models in relief.—4. Method of engraving the block.—5. Antiquity of this art.—6. Invention of movable type.—7. Use of movable types for printing successive books or parts of a book.—8. Process of printing.—9. Composition.—10. Quadrats.—11. Use of the chase.—12. Imposing.—13. Reading and correcting.—14. Successive operations in printing.—15. Inking.—16. Inking-rollers.—17. Stanhope press.—18. Printing-machines.—19. General description of them.—20. Single printing-machines.—21. Double printing-machines.—22. Perspective view and description of Applegath and Cowper's double printing-machine.

1. It is a remarkable fact, that printing, which has so far transcended all other arts in the influence it has exerted in the advancement of knowledge and the progress of the human race, owes almost nothing to the class devoted professionally to letters and the sciences, and on whom it has, nevertheless, bestowed the largest measure of advantage.

2. Printing, in its most general sense, is the name given to all processes in the arts, by which the same forms or characters are indefinitely multiplied, by the impressions of the surface upon which they are formed repeatedly and successively, upon the surface to which they are to be transferred. Thus, in calico printing, the same figures are transferred in rapid succession to different pieces of cloth, or to different parts of the same piece, by means of blocks or rollers, upon which the figures are produced, either in *relief* or *intaglio*, that is, either in raised or sunken characters. In such cases the blocks, or rollers, are pressed in succession on the surface of the cloth to be printed, being however previously smeared with colouring matter. In the printing of copper or steel engravings, the design is produced by the engraver in lines sunk in the surface of the copper or steel by the engraving tool. These lines being filled with the printing-ink, and all other parts being carefully cleaned, the plate is impressed on the paper with an intense pressure by means of a press specially adapted to that purpose. The paper being previously moistened, absorbs the ink from the lines in which it is deposited, and exhibits after the impression a perfect copy of the engraving,—the sunken lines of the engraving being represented on the paper by corresponding lines in ink.

3. In wood-engravings, and in ordinary book-printing, the original from which the impressions are taken is in relief. A model in relief of the page to be printed is formed in metal called *type-metal*, consisting of lead rendered hard by being alloyed with a small proportion of antimony. The surface being smeared with the colouring-matter called *printing-ink*, is impressed upon the paper, and a *fac-simile* of the original relief is thus produced.

4. In the earliest and rudest attempts at printing, a manuscript page was attached to the surface of a block of wood, which was carved into relief corresponding with the characters of the manuscript. The impression produced by this means was necessarily a *fac-simile*, more or less accurate, of the manuscript itself.

5. The method of printing by means of blocks of wood, or metal, carved in relief, is the earliest example on record of the practical use of the art which, in its more improved state, has exercised so important an influence upon civilisation. According to some antiquarian authorities, the art of producing characters in this way may be traced as far back as the building of Babylon. The characters found upon bricks, taken from the supposed site of that city, having been undoubtedly printed by the method here described. We are in possession of metal stamps, with words engraved in relief, which the Romans made use of to mark their

various articles. If the modern art of making paper had been known in those remote times, it is very probable that the art of printing books would have existed at a much earlier date than that of its actual commencement, for with the same kind of stamps precisely, as those by which the Roman tradesmen marked their wares, books might have been printed, and the same engravings which adorned the shields and pateras of ancient times might, by the aid of paper, have spread the intelligence of Greece and Italy over the world.

According to Du Halde and certain missionaries, the art of printing from blocks carved in relief was practised in China fifty years before the Christian era; and, from the early commercial intercourse of the Venetians with that country, there is reason to believe that the knowledge of this art, in its application to the multiplying of books, was originally derived from thence, for Venice is the first place in Europe in which it is recorded to have been practised.

Its first application was to the production of playing cards and religious prints, and when the art was first extended to books they were printed by carving each page upon a separate block. This process of carving the characters in relief, which was probably executed by attaching the manuscript to the face of the block and engraving from the manuscript, will afford an easy and obvious explanation of the diversity of characters found in ancient books printed from such blocks, and will explain the great similarity which exists between books thus printed and manuscripts. This similarity was increased by their being printed on one side of the paper only, the indentation produced by the impression being removed by burnishing the back. Two leaves were then pasted together, making such a perfect *fac-simile* of the manuscript, as to require, even at the present day, great discrimination and much chemical skill to distinguish such books from real manuscripts; and as they have no printers' names, dates, or places affixed to them, it is impossible to ascertain by whom, or when, or where they were executed. The fabrication of these pseudo-manuscripts involved the first introduction of the art of printing.

6. **Movable Types.**—About the middle of the fifteenth century the art of printing in this rude manner acquired considerable extension; but as each separate work required to have separate blocks for each page, and since the blocks for one work were altogether useless for another, the printers soon began to feel the inconvenience arising from the storage of such numerous collections of blocks, to say nothing of the expense of carving them. They were, therefore, stimulated to seek for some method less costly and cumbrous, by which the models in relief of the pages could be

produced, and so that the materials of the model of any one page might be afterwards useful, in the formation of the models of other pages. The discovery of the means of accomplishing this object by movable types constitutes the most important epoch in the history of printing, and is sometimes even regarded, in all essential respects, as the invention of printing itself. After it had undergone some successive improvements, it resolved itself into the production of models in relief of the letters of the alphabet, formed upon the extremities of small bars of metal, which being properly selected and placed in juxtaposition, formed the words and letters of a page. Such are the *types* of the modern printer.

The honour of the invention of movable types has been disputed by two cities, Haarlem and Mentz. The claims of Haarlem rest chiefly upon a statement of Hadrien Junius, who gave it upon the testimony of Cornelius, alleged to be a servant of Lawrence Coster, for whom the invention is claimed. The claims of Mentz, which appear to be more conclusive, are in favour of Peter Schæffer, the assistant and son-in-law of John Faust, better known as Dr. Faustus. The first edition of the *Speculum humanæ salvationis* was printed by Coster at Haarlem, about the year 1440, and is one of the earliest productions of the press of which the printer is known. The celebrated Bible, commonly known as the Mentz Bible, without date, is the first important specimen of printing with movable metal types. This was executed by Gutenberg and Faust, or Fust, as it is sometimes spelt, between the years 1450 and 1455. The secret of the method then becoming known, presses were speedily established in all parts of Europe, so that before the year 1500 there were printing-offices in upwards of 220 different places in Austria, Bavaria, Bohemia, Calabria, the Cremonese, Denmark, England, Flanders, France, Franconia, Frioul, Geneva, Genoa, Germany, Holland, Hungary, Italy, Lombardy, Mecklenberg, Moravia, Naples, the Palatinate, Piedmont, Poland, Portugal, Rome, Sardinia, Upper and Lower Saxony, Sicily, Silesia, Spain, Suabia, Switzerland, Thessalonica, Turkey, Tuscany, the Tyrol, Venice, Verona, Westphalia, Wurtemberg, &c.

This vast and rapid extension of the art, combined with the skill which the earlier printers displayed in it, seems to be totally incompatible with the date assigned to the invention, and it is more probable, that the art having been long practised in private under continued attempts at secrecy, it at length broke into publicity after it had already attained a considerable degree of perfection.

7. When the page of a book is formed by properly combining

the types, and a sufficient number of copies of it produced by the process of printing, the types which form it are disengaged and separated and used to form other pages of the same or other books. Thus, while in the first attempts at printing, each model of letter in relief never did any other duty than the printing of the very book for which it was formed, the type of each letter in printing with movable types is transferred from page to page, and is used successively in the printing of an indefinite number of pages of the same or different works.

8. **The process of printing,** then, consists in a certain succession of operations, the first of which is putting together the types so as to form lines and pages; the second, putting together these pages in such a manner, that when impressed upon sheets, and the sheets folded, they will succeed each other in the proper order. The subsequent operations of folding, stitching, and combining these sheets together, so as to form a volume, is the business of the bookbinder.

9. **Composition.**—The process of putting the types together is called *composing*, and the person who performs this operation is called a *compositor*. He stands before an inclined desk, as shown in the view of the composing-room (fig. 1), which is divided into a number of compartments of different sizes, A, B, in each of which are placed a certain number of types of a particular letter. By practice he learns without hesitation to direct his hand to the compartment which contains the letter he wants, without removing his eye from the manuscript which lies before him. He holds in his left hand an instrument called a *composing-stick*, which is so formed as to receive the types in successive juxtaposition, until the requisite number have been placed to form a complete line, after which another line is composed in like manner, and thus line after line is composed until a complete page has been formed. The spaces between words are made by the insertion of small bars called *quadrats*, similar to those of type, but having no letter cast upon their ends, and the spaces between line and line are produced by the insertion of thin plates of metal called *leads*. When the lines are considerably separated from one another, they are accordingly said to be "leaded." When a page has been composed the compositor ties a cord round it, called a *page-cord*, to hold the types of which it consists provisionally together, and placing it apart, proceeds to form another page, and so on.

10. Since every line of the same page must necessarily have the same length, whether the types which compose it fill out that length or not, any deficient space is filled by quadrats placed at the most convenient points between the words.

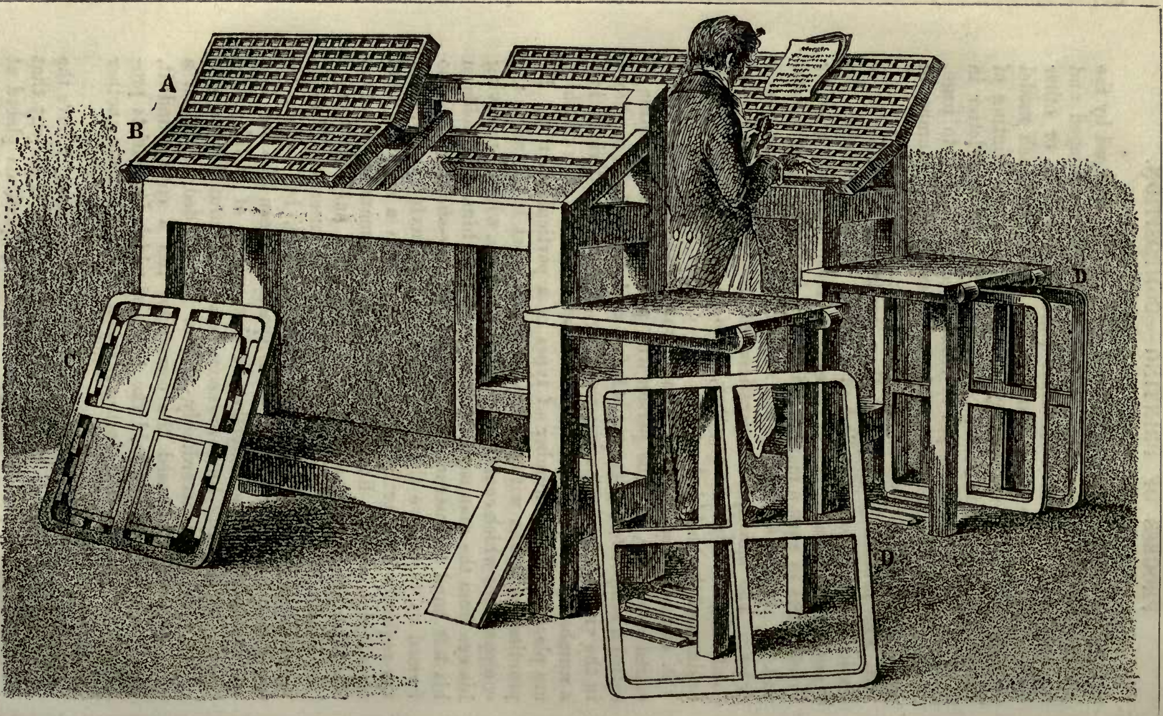


Fig. 1.—Composing Room.

In like manner the blank parts of last lines of paragraphs are filled with quadrats.

11. When the pages of one side of a sheet have been thus composed, they are placed in the divisions of an iron form called a *chase*, C, D, several of which appear in the view of the composing-room, fig. 1. These chases, of course, vary in their form and mode of division according to the size and number of the pages which form a sheet. We have here supposed the pages which are composed and arranged in the chase to be those which are required to be printed on one side of the sheet. A similar number are composed and similarly put together in another chase, being those to be printed on the other side of the sheet.

12. **Imposing.**—The process of arranging the pages in the chase is called "imposing."

13. **Readers and Correctors.**—When the pages composing each side of the same sheet have been thus "*imposed*," and the types securely fastened in the chase by proper wedges, the chases are brought to a printing-press, which will be presently described, where a single impression is taken from them, called the *first proof*, which, being properly folded, is taken to a person called the "*reader*," who has always a boy capable of reading the manuscript to assist him. While the boy reads the manuscript, the "*reader*" follows him upon the proof, which he carefully examines, and upon which he marks the errors of the compositor. The proof is then returned to the compositor, who corrects the errors indicated by the reader, and a second impression is then taken with more care, and generally on better paper. This is called a *clean proof*, and is again examined by the reader to ascertain whether the compositor has corrected all the errors previously indicated; and if there are none uncorrected, the proof is then sent to the author. In good printing-offices there are few or no press errors found in the author's proof, those corrected by him being in general errors which had been overlooked in his own manuscript, or corrections of language suggested to him in the revision of the sheet.

14. After the sheet has received the correction of the author, the form to be printed is laid upon a horizontal table, with the faces of the types uppermost, and the following operations are executed:—1st. Printing-ink is applied to the faces of the type, so evenly that there shall be no blotting or inequalities in the printing; 2nd. The sheet of paper to be printed is laid upon the form so as to receive the impression of the type in its proper position, and in the centre of it; 3rd. This paper is urged upon the type by a sufficient pressure to enable it to receive the printed characters, such pressure, however, not being so great as to cause

the type to penetrate or deface the paper; 4th. The paper is, in fine, when thus printed, withdrawn from the type and laid upon a table, where the printed sheets are collected.

15. **Inking.**—In the old process these operations were performed by two men, one of whom was employed to ink the types, and the other to print. The former was armed with two bulky inking-balls, consisting of a soft black substance of leathery appearance, spherical form, and about twelve inches in diameter. He flourished these with dexterity, dabbed them upon a plate smeared with ink, and then with both hands applied them to the faces of the types until the latter were completely charged with ink. This accomplished, the other functionary—the pressman—having prepared the sheet of paper while the type was being inked, turned it down upon the type, drew it under the press, and with a severe pull of the lever gave the necessary pressure by which the paper took the impression of the type. A contrary motion of the apparatus withdrew the type from under the press, and the pressman, removing the paper now printed, deposited it upon a table placed near him to receive it. The same series of operations was then repeated for producing the impression of another sheet and so on. In this manner two men in ordinary book-work usually printed at the rate of 250 sheets per hour on one side.

16. **Inking-rollers.**—One of the first improvements which took place upon this apparatus consisted in the substitution of a cylindrical roller for the inking-balls. This roller was mounted with handles, so that the man employed to ink the type first rolled it upon a flat surface smeared with ink (fig. 2), and having thus charged it, applied it to the type form, upon which he rolled it in a similar manner, thus transferring the ink from the roller to the faces of the type. The substitution of these inking-rollers for the inking-balls constituted one of the most important steps in the modern improvement of the art of printing. The rollers were composed of a combination of treacle and glue, and closely resembled caoutchouc in their appearance and qualities.

17. **Stanhope Press.**—The process by which these operations were executed, assumed in the course of years a great variety of improved forms, and one of the most celebrated and most universally adopted having been supplied by the inventive genius of Earl Stanhope, has accordingly retained his name, and is known as the *Stanhope press.* This machine, which, resembling all other improved presses in its general features, and serving, therefore, as an example of hand-presses in general, is shown in fig. 3. The two principal parts of the machine are *first*, that which produces the pressure, and the *second*, that which supports the paper. The former is a massive frame of cast iron, formed in a single

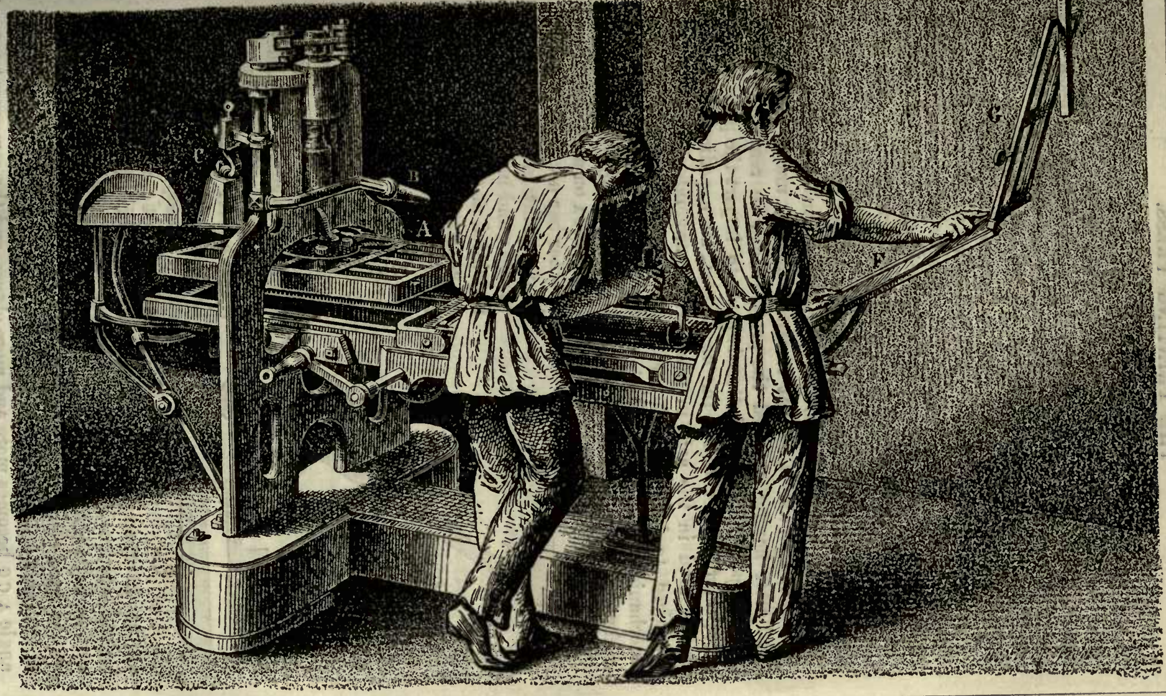
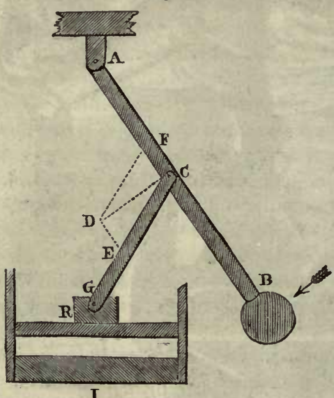


Fig. 3.—Stanhope Press.

piece, in the upper part of which is a nut, in which a screw moves—the point of which acts upon the upper end of a slider, which is fixed into a dovetailed groove formed between two vertical bars of the frame. This slider has attached to its lower end a square plate, called the *platten*, which rises and falls according as the screw is turned in the one direction or the other. The weight of the platten fig. 3, A, and slider, which is considerable, is counterpoised by a heavy weight C suspended by a lever behind the press. The flat table, called the *carriage*, upon which the form of types is laid, is moved backwards and forwards by means of a winch, which appears in fig. 3. By means of this winch, and the rack or band with which it is connected, the carriage with the type form can be moved by the pressman alternately backwards and forwards, so that it can be brought under the platten, and after having received the pressure, can be removed back to its first position. The platten is made to impart the pressure by means of a lever called the *knee lever*, an expedient which is much used in the arts in cases where any intense pressure is required to be produced through a very limited space. The mechanical effect of this species of lever will be understood by a reference to fig. 4, where A B is a metal rod, having a fixed point of support A on which it works; another bar G C is jointed to it at C, a point intermediate between A and B. This bar C G is jointed at G to a plate such as R, or any other object to which it is desired to transmit any intense force acting through a very limited space, as, for example, in the present case, where the paper is pressed upon the type by a plate which is driven upon it by a sudden and severe force. The handle B of the lever being pressed in the direction of the arrow, exerts a corresponding pressure on the point C, which is driven in the direction C D perpendicular to A B. This motion C D is resolved into two by the parallelogram of forces, one in the direction C E, and the other in the direction C F; the latter exerts pressure on the fixed point A, and the other acts upon the plate R by means of the joint G forcing it downwards. As the joint C advances, the angle A C G becomes more and more obtuse, and the component C E

Fig. 4.



of the force acting at B, bears a rapidly increasing proportion to the force itself, so that when the levers A C and C G come nearly into a right line, the pressure exerted at B is augmented at G in an almost infinite proportion.

In working the press, the pressman places a sheet of paper to be printed upon the frame F, called the *tympan*, where it is held in its place by turning over it the frame G, which is supplied with rods or cords corresponding to the spaces between the pages of the form. While the pressman is thus employed, his assistant is engaged in inking the types with a roller, as shown in fig. 3. When this has been accomplished, the pressman turns down the tympan carrying the paper upon the types, and then, by turning the handle, moves the carriage with the type form upon it under the platten, and applying his hand to the handle above him presses the platten down upon the tympan carrying the paper, and by means of the knee lever produces a sudden and severe pressure by which the paper receives the impression of the type. The handle is then moved in a contrary direction, the platten being raised from the type form, and by turning the other handle the carriage with the type form is removed from under the platten. The pressman then raises the tympan from the types, and taking the printed sheet off, replaces it by a fresh blank sheet, over which he turns the frame as before; and while he is performing this operation, his assistant is occupied in inking the types, after which the same operations are performed, and another sheet is printed, and so on.

18. **Printing Machines.**—The printing presses which served the purposes of publication for some hundred years, during which they received no other improvements than such as might be regarded merely as modifications in the detail of their mechanism, have been almost entirely superseded by engines of vastly increased power and improved principles of construction. Although these admirable machines differ one from another in the details of their mechanism, according to the circumstances under which they are applied, and the power they are expected to exert, they are nevertheless characterised by certain common features.

19. The form to be printed is laid in the usual manner upon a perfectly horizontal table, with the faces of the types uppermost; and upon the same table, in juxtaposition with the form, and level with the faces of the types, or nearly so, is placed a slab upon which a thin and perfectly regular stratum of printing-ink is diffused; the table thus carrying the form and inking-slab is moved by proper machinery right and left horizontally, with a reciprocating rectilinear motion through a space a little greater than the length of the form.

Above the form and slab are mounted, also in juxtaposition, a large cylinder or drum, which carries upon it the sheet of paper to be printed, and three or four inking-rollers similar to that already described. There are also three or four other rollers in juxtaposition with the latter, one of which supplies ink to the others, which severally spread it in a uniform stratum upon the slab. The paper-cylinder and the inking and diffusing rollers are so mounted, that when the horizontal table, carrying the form and inking slab, moves alternately backwards and forwards under them, they roll upon it.

In this way, when the table is moved towards the rollers, the form, passing under the inking-rollers right and left, receives from them the ink upon the face of the type; and at the same time the slab, moving backwards and forwards under the diffusing rollers, receives from them, upon its surface, the proper stratum of ink to supply the place of that which was taken from it by the inking-rollers.

20. **Single Printing Machines.**—When the table is moved alternately towards the other side, the form, with the types already inked, passes under the cylinder carrying the paper, the motion of which is so regulated as to correspond exactly with the rectilinear motion of the table carrying the form. The cylinder is urged upon the type with a regulated force, sufficient and not more than sufficient, to impress the type upon the paper.

The sheets of paper are supplied in succession to the cylinder, and held evenly upon it by bands of tape while they pass in contact with the type. After receiving the impression of the type, the tapes which bound them are separated, and the printed sheets discharged.

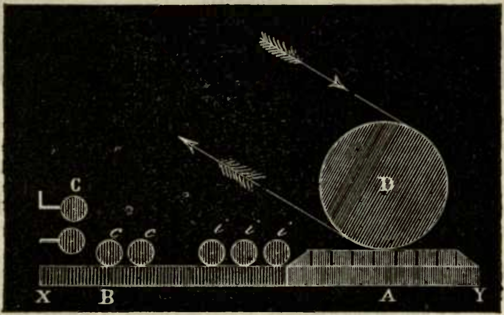
Such is the general principle of single printing-machines.

21. **Double Printing Machines.**—In these the table which is moved alternately right and left, carries two forms, one corresponding to the pages to be printed on one side of the sheet, and the other to those to be printed on the other side. There are also two inking-slabs, one to the left of the left-hand form, and the other to the right of the right-hand form. There are also two paper cylinders, and two sets of inking and diffusing-rollers. Each sheet of paper to be printed, being held between tapes, as already described, is carried successively round the two cylinders, being so conducted, in passing from one to the other, that one side of it passes in contact with, and is printed by, one form, and the opposite side by the other form. The proportion of the motions is so nicely regulated, that the impression of each page or column made on one side of the paper, corresponds exactly with that of the corresponding page or column on the other side.

This general description will be more clearly understood by reference to the following illustrative diagrams:—

Fig. 5 illustrates the operation of a single printing-machine. The form A and the inking-slab B, are placed on a horizontal table; above them is the paper-cylinder D, the inking-rollers *i i i*, the diffusing-rollers *c c*, and the rollers C, which supply the ink to the diffusing-rollers. The first of these, C, is called the ductor roller. When the table X Y is moved towards the left, from Y to X, the form A passes under the inking-rollers *i i i*, and receives ink from them on the faces of the type; at the same time the slab B passes under the diffusing-rollers *c c*, and receives from them a supply of ink to replace what it has just given to the inking-rollers.

Fig. 5.



When the table is moved in the contrary direction, from X towards Y, the form once more passes under the inking-rollers, and afterwards under the paper-cylinder, which being pressed upon it, while it moves in exact accordance with it, the types discharge upon the paper the ink they have just received from the rollers; and the printing of the paper being thus effected on one side, the sheet is discharged from the tapes. The table is then again moved to the left, and the types are again inked, and the same effects ensue as have already been described.

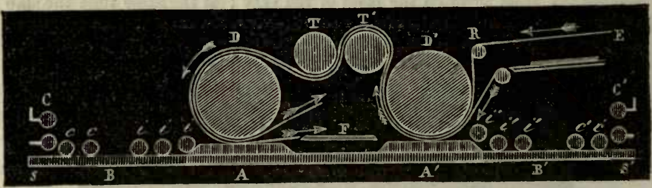
In this manner sheet after sheet is printed.

The inking and diffusing-rollers rest upon the slab and types by their weight, the axes projecting from their ends being inserted in slits formed in upright supports, attached to opposite sides of the frame which supports the moving table. The two upright pieces in which the axes of each roller are inserted, are not placed in exact opposition to each other; the consequence of which is, that the rollers are placed with their axes slightly inclined to the sides of the table. This arrangement is attended with a very important effect: for, in consequence of the friction or adhesion of the rollers with the slab, they are moved alternately in contrary directions with the longitudinal motion across the table. This motion, combined with their rolling motion upon the

slab, aids materially in diffusing the ink in a perfectly uniform stratum.

An illustrative diagram of a double printing-machine is shown in fig. 6, where D and D′ are the two paper-cylinders; A and A′, the two forms; *i i i* and *i′ i′ i′*, the inking-rollers; *c c* and *c′ c′*, the diffusing-rollers; and C and C′ the ductor-rollers. The pile of paper placed on the table E, is

Fig. 6.



supplied sheet by sheet to the tapes between which it is held; and being passed over the roller R, and under the cylinder D′, it receives the impression of the types of the form A′; it then passes successively over the roller T′, under T, and round the cylinder D, at the lower point of which its unprinted side comes into contact with the types of the form A, by which it is printed; after which, the tapes opening, it is thrown out by the centrifugal force upon the receiving table F.

It will be apparent by the figure, that while the sheet is printed on one side by the form A′, the form A is passing between the inking-rollers *i i i*, and the slab B; and on the contrary, while the paper is printed on the other side by the form A, the form A′ is passing between the inking-rollers *i′ i′ i′* and the slab B′.

In this manner, by each alternate motion from right to left, and from left to right, a sheet is printed on both sides.

22. A perspective view of a double-acting printing machine, as constructed by Messrs. Applegath and Cowper, is shown in fig. 7.

A boy, called the *layer-on*, E, standing at an elevated desk, pushes the paper, sheet by sheet, towards the tapes, which, closing upon it, carry it over a roller R, passing under which it is carried to the right of the cylinder D, under which it passes, and being carried up to the left of it, passes successively over the roller T, under the roller T′, over the cylinder D, and drawn along its left side, after which it passes under it, and is flung into the hands of a boy, F, called the *taker-off*, seated before a table placed between the two cylinders D and D′, upon which he disposes the sheets as he receives them.

In this manner the layer-on feeds the machine in constant succession with blank sheets, which, being carried under the cylinder D, are printed on one side, and afterwards under the cylinder D′, are printed on the other, when they are received by the taker-off.

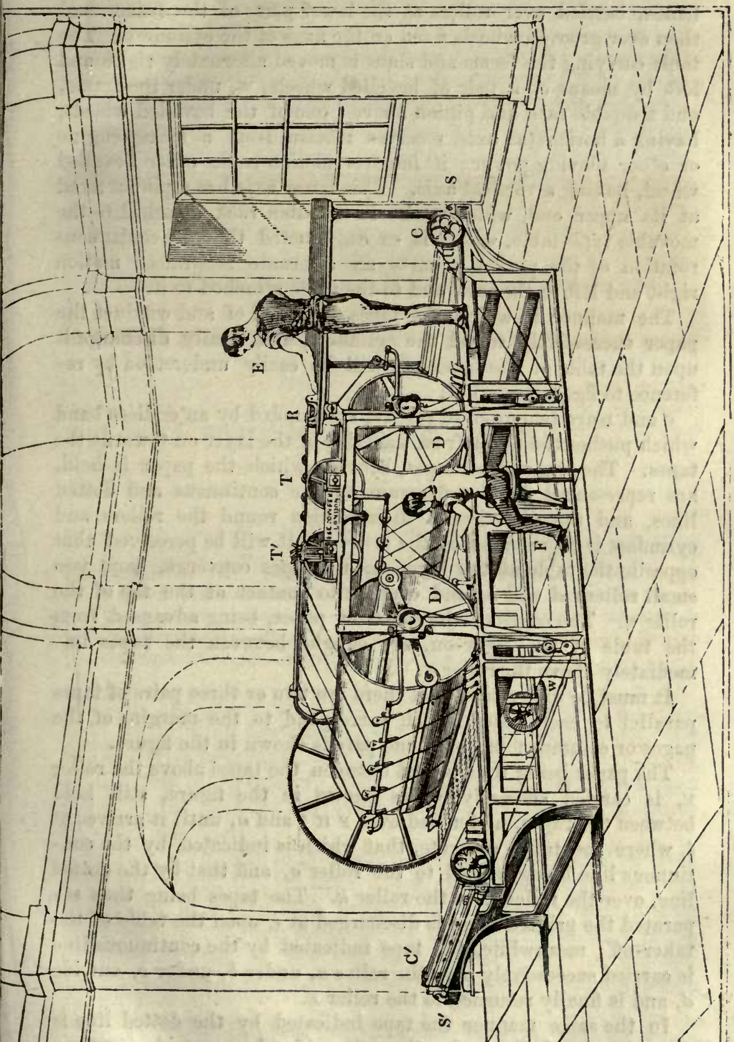


Fig. 7.—Applegath and Cowper's Double Printing Machine.

The ductor-rollers, C and C′, are kept in revolution by endless bands, carried over rollers at the lower parts of the frame, and then over grooved wheels fixed on the axes of the cylinders. The table carrying the forms and slabs is moved alternately right and left by means of a pair of bevelled wheels, W, under the frame, and a double rack and pinion above; one of the bevelled wheels, having a horizontal axis, receives motion from a steam-engine or other moving power; it imparts motion to the other bevelled wheel, having a vertical axis. This latter axis has a pinion fixed at its upper end, which works in a double rack attached to the movable type-table, which is so constructed that the continuous rotation of the pinion imparts an alternate rectilinear motion right and left to the rack and to the table attached to it.

The manner in which the tapes lay hold of and conduct the paper successively round the cylinders, and finally discharge it upon the table of the taker-off, will be easily understood by reference to fig. 8, page 177.

C and D are two grooved rollers, surrounded by an endless band which pushes the paper from the table of the layer on towards the tapes. The two endless tapes, between which the paper is held, are represented in the diagram by the continuous and dotted lines, and the direction of their motion round the rollers and cylinders is represented by the arrows. It will be perceived that opposite the table of the layer-on, the tapes converge, from two small rollers *d* and *h*, and come into contact at the top of the roller E. The edges of the sheets of paper, being advanced from the table of the layer-on, are caught between the tapes immediately above the roller E.

It must be understood that there are two or three pairs of tapes parallel to each other, which correspond to the margins of the pages or columns; but only one pair is shown in the figure.

The paper being thus seized between the tapes above the roller E, is carried successively, as shown in the figure, still held between the tapes, under and over F H I and G, until it arrives at *i*, where the tapes separate, that which is indicated by the continuous line being carried to the roller *a*, and that by the dotted line, over the roller *i*, to the roller *k*. The tapes being thus separated the printed sheet is discharged at *i*, upon the table of the taker-off; meanwhile, the tape indicated by the continuous line is carried successively over the roller *a*, under *b*, under *c*, outside *d*, and is finally returned to the roller E.

In the same manner the tape indicated by the dotted line is carried successively under the roller *k* and *m*, outside *n*, over *v* and *h*, from which it returns to E, where it again joins the other tape proceeding from *d*.

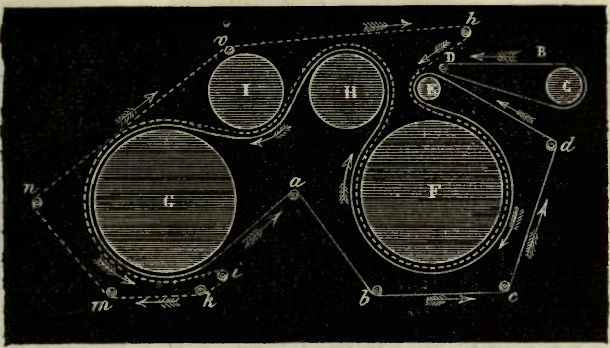


Fig 8.

THE PRINTING PRESS.

CHAPTER II.

23. The first machines constructed upon this improved principle for printing newspapers, were erected at the printing office of *The Times* newspaper, and it was announced in that journal, on the 28th of November, 1814, that the sheet which was then placed in the hands of the reader, was the first printed by steam-impelled machinery.

By this, with some improvements which the apparatus received soon afterwards, the effective power of the printing-press was augmented in a very high proportion. With the hand-presses previously in use, not more, as we have seen, than 250 sheets could be printed on one side in an hour. Each of the two machines erected at *The Times* office produced 1800 impressions per hour.

24. **Further Improvement.**—The power of the printing-machine constructed upon this principle was soon after augmented, by increasing the number of printing-cylinders to

four, the principle of the machine, however, remaining the same.

The manner in which this was accomplished will be easily understood by the aid of the illustrative diagram, fig. 9, where 1, 2, 3, and 4, are the printing-cylinders: P P P′ P′, are the tables of the four layers-on, and O O O′ O′, lead to those of the four takers-off. The course followed by the sheets of paper, in passing to and from the cylinders, are indicated by the arrows. Inking rollers are in this case placed at R, between the printing-cylinders; the two type-forms are inked twice, while they move from right to left, and twice again while they move from left to right. The printing-cylinders are alternately let down upon the type and raised from them in pairs; while the type-table moves from left to right, the cylinders 1 and 3 are in contact with the table, the cylinders 2 and 4 being raised from it, and, on the contrary, when it moves from right to left, the cylinders 2 and 4 are in contact with it, 1 and 3 being raised from it.

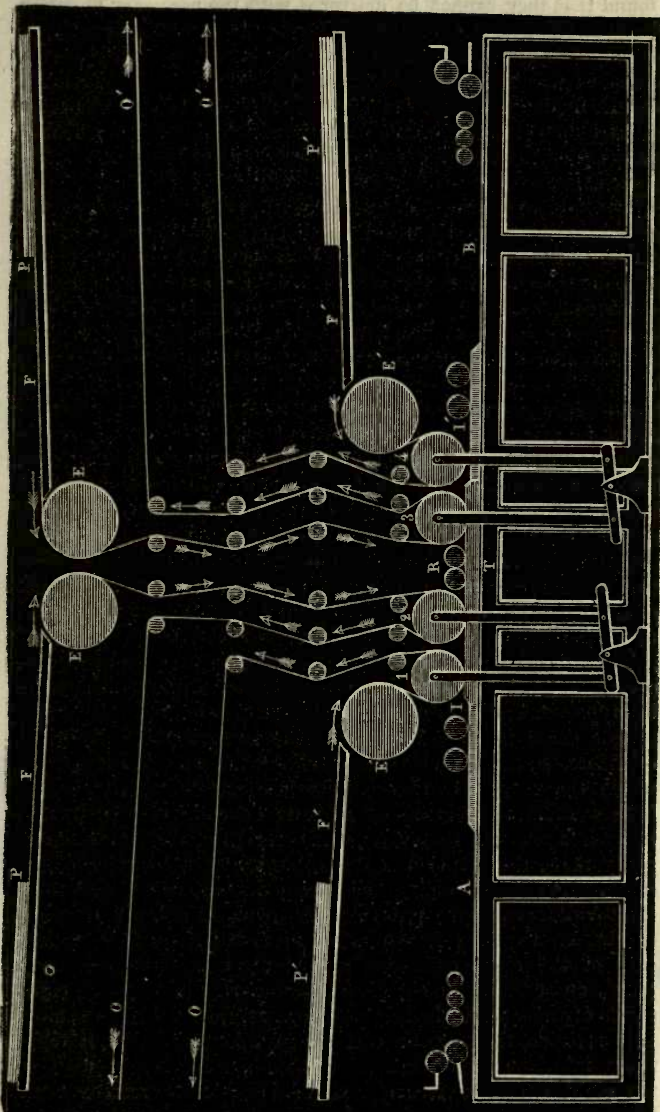
By this improvement, which was adopted in *The Times* office in 1827, the proprietors of that journal obtained the power, then unprecedented, of printing from 4000 to 5000 sheets per hour on one side of the paper. By this means they were enabled to satisfy the demands of a circulation amounting to 28000.

In reference to newspaper-printing, it must be here observed that the great object to be attained, is to increase the celerity by which printing on one side only of the sheet can be augmented. It is found convenient so to arrange the letter-press that the matter appropriated to one side of the sheet shall be ready for press at an early hour, and may be printed before the contents of the other side, in which the most recent intelligence is included, can be prepared. Hence the advantage of using machines adapted to print one side only with the most extreme celerity for newspapers.

25. **"Times" Printing-machine.**—This machine continued to serve the purposes of *The Times* newspaper until a later epoch, when again the exigencies of the press exceeded even its immense powers, and another appeal was made to the inventive genius of Mr. Applegath. It was, in short, necessary to provide a machine by which at least 10000 sheets an hour could be worked off from a single form!

In considering the means of solving this problem, it is necessary to observe, that whatever expedient may be used, the sheets of paper to be printed must be delivered one by one to the machine by an attendant. After they once enter the machine they are carried through it and printed by self-acting machinery. But in the case of sheets so large as those of the newspapers, it is

Fig. 9.



found that they cannot be delivered with the necessary precision by manipulation at a more rapid rate than two in five seconds, or twenty-five per minute, being at the rate of 1500 sheets per hour. Now, in this manner, to print at the rate of 10000 per hour, would require seven cylinders, to place which so as to be acted upon by a type-form moving alternately in a horizontal frame, in the manner already described, would present insurmountable difficulties.

In the face of these difficulties, Mr. Applegath, to whom the world is indebted for the invention of *The Times* printing-machine, decided on abandoning the reciprocating motion of the type-form, arranging the apparatus so as to render the motion continuous. This necessarily involved circular motion, and accordingly he resolved upon attaching the columns of type to the sides of a large drum or cylinder, placed with its axis vertical, instead of the horizontal frame which had been hitherto used. A large central drum is erected, capable of being turned round its axis. Upon the sides of this drum are placed vertically the columns of type. These columns, strictly speaking, form the sides of a polygon, the centre of which coincides with the axis of the drum, but the breadth of the columns is so small compared with the diameter of the drum, that their surfaces depart very little from the regular cylindrical form. On another part of this drum is fixed the inking-table. The circumference of this drum in *The Times* printing-machine measures 200 inches, and it is consequently 64 inches in diameter.

The general form and arrangement of the machine are represented in fig. 10, where D is the great central drum which carries the type and inking tables.

This drum in *The Times* machine is surrounded by eight cylinders, R, R, &c., also placed with their axes vertical, upon which the paper is carried by tapes in the usual manner. Each of these cylinders is connected with the drum by toothed-wheels, in such a manner that their surfaces respectively must necessarily move at exactly the same velocity as the surface of the drum. And if we imagine the drum, thus in contact with these eight cylinders, to be put in motion, and to make a complete revolution, the type-form will be pressed successively against each of the eight cylinders, and if the type were previously inked, and each of the eight cylinders supplied with paper, eight sheets of paper would be printed in one revolution of the drum.

It remains, therefore, to explain, first, how the type is eight times inked in each revolution; and, secondly, how each of the eight cylinders is supplied with paper to receive their impression.

Beside the eight paper-cylinders are placed eight sets of inking rollers; near these are placed two ductor rollers. These ductor rollers receive a coating of ink from reservoirs placed above

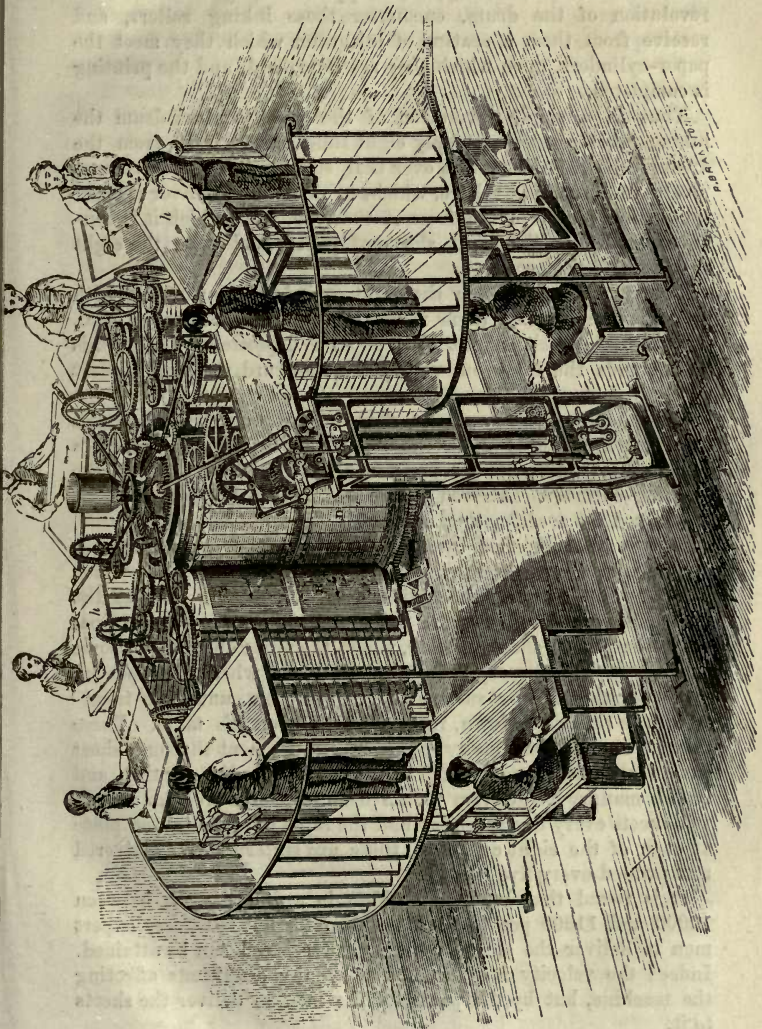


Fig. 10.—"Times" Printing Machine.

them. As the inking-table attached to the revolving drum passes each of these ductor-rollers, it receives from them a coating of ink. It next encounters the inking rollers, to which it delivers over this coating. The types next, by the continued revolution of the drum, encounter these inking rollers, and receive from them a coating of ink, after which they meet the paper-cylinders, upon which they are impressed, and the printing is completed.

Thus in a single revolution of the great central drum the inking-table receives a supply eight times successively from the ductor-rollers, and delivers over that supply eight times successively to the inking rollers, which, in their turn, deliver it eight times successively to the faces of the type, from which it is conveyed finally to the eight sheets of paper held upon the eight cylinders by the tapes.

Let us now explain how the eight cylinders are supplied with paper. Over each of them is erected a sloping desk, *h*, *h*, &c., upon which a stock of unprinted paper is deposited. Beside this desk stands the layer-on, who pushes forward the paper, sheet by sheet, towards the tapes.

These tapes, seizing upon it, first draw it down in a vertical direction between tapes in the eight vertical frames, until its edges correspond with the position of the form of type on the printing-cylinder. Arrived at this position, its downward motion is stopped by a self-acting apparatus provided in the machine, and it is then impelled by vertical rollers towards the printing cylinder, these rollers having upon them marginal tapes which carry the paper round the cylinder, from which it receives the impression of the types. After this the central and lower marginal tapes dismiss the sheet of paper, which the upper ones only become charged with, and carry it to its proper place, where the tapes are stopped with the paper suspended between them, until the taker-off draws the sheets down, ranging them upon his table. These movements are continually repeated; the moment that one sheet passes from the hands of the layer-on, he supplies another, and in this manner he delivers to the machine at the average rate of two sheets every five seconds; and the same delivery taking place at each of the eight cylinders, there are sixteen sheets delivered and printed every five seconds.

It is found that by this machine in ordinary work between 10000 and 11000 per hour can be printed; but with very expert men to deliver the sheets, a still greater speed can be attained. Indeed the velocity is limited, not by any conditions affecting the machine, but by the power of the men to deliver the sheets to it.

In case of any misdelivery a sheet is spoilt, and, consequently, the effective performance of the machine is impaired. If, however, a still greater speed of printing were required, the same description of machine, without changing its principle, would be sufficient for the exigency; it would be necessary that the types should be surrounded with a greater number of printing cylinders.

It may be right to observe, that the cylinders and rollers are not uniformly distributed round the great central drum; they are so arranged as to leave on one side of that drum an open space equal to the width of the type form. This is necessary in order to give access to the type form so as to adjust it.

One of the practical difficulties which Mr. Applegath had to encounter in the solution of the problem, which he has so successfully effected, arose from the shock produced to the machinery by reversing the motion of the horizontal frame, which, in the old machine, carried the type-form and inking-table, a moving mass which weighed twenty-five hundred weight. This frame had a motion of 88 inches in each direction, and it was found that such a weight could not be driven through such a space with safety, at a greater rate than about forty-five strokes per minute, which limited its *maximum* producing power to 5000 sheets per hour.

Another difficulty in the construction of this vast piece of machinery was so to regulate the self-acting mechanism that the impression of the type-form should always be made in the centre of the page, and so that the space upon the paper occupied by the printed matter on one side may coincide exactly with that occupied by the printed matter on the other side.

The type-form fixed on the central drum moves at the rate of about 80 inches per second, and the paper is moved in contact with it of course at exactly the same rate. Now, if by any error in the delivery or motion of a sheet of paper, it arrive at the printing-cylinder 1-80th part of a second too soon or too late, the relative position of the columns will vary by 1-80th part of 80 inches—that is to say, by one inch. In that case the edge of the printed matter on one side would be an inch nearer to the edge of the paper than on the other side.

This is an incident which rarely happens, but when it does, a sheet, of course, is spoilt. In fact, the waste from that cause is considerably less in the present vertical machine than in the former less powerful horizontal one.

The vertical position of the inking-rollers, in which the type is only touched on its extreme surface, is more conducive to the goodness of the work than the horizontal machine, where the

inking-rollers act by gravity; also any dust shaken out of the paper, which formerly was deposited upon the inking-rollers, now falls upon the floor.

With this machine 50000 impressions have been taken without stopping to brush the form or table.

26. **Marinoni's Newspaper Printing-press.**—Messrs. Marinoni and Co., of Paris, have, within the last few years, constructed improved printing presses for newspapers of large circulation, several of which have been erected and brought into operation in the printing-office of the Paris journal *La Presse*. This printing-machine, which is capable of working off 6000 copies per hour, printed on both sides of the paper, is represented in fig. 11. It will be perceived that eight men are employed in the process, four layers-on and four takers-off. The machine is double, the parts at each side of a vertical line drawn through the axis of the fly-wheel being perfectly similar. The manner in which the sheets pass to and from the printing-rollers will be more readily understood by fig. 12, where A is the upper and A′ the lower delivering-board, and B the upper and B′ the lower receiving-board on the right, the two delivering and receiving-boards on the left being similarly placed. The motion of the sheets, as they are conducted to and from the rollers by the tapes, is indicated by arrows, and the course followed by each sheet from the moment it leaves the delivering-board until it arrives at the receiving-board, is indicated by the numbers 1, 2, 3, 4, &c. Thus, the sheet delivered from the board A is taken by the tapes which pass round the roller M, and carried from 1 to 2. Arriving at the lower roller, it passes, as shown by the arrow, between the rollers, 3, and is carried from 4 under the printing-roller I, where it is printed on one side, after which it is carried up between the tapes to 5, from whence it is discharged between the tapes of 6, and carried up over the roller R at 7, from which it is carried down between the tapes 8, and thrown, as shown by the arrow, to the tapes 9, by which it is again carried under the roller and printed on the other side; after which it is carried up successively between the tapes 10 and 11 to 12, and finally discharged from 13 at 14 upon the receiving-board B.

The sheet delivered from the lower receiving-board A′, follows a course precisely similar, entering at 1′ and passing round the printing-roller at 2′ 3′, from which it passes between the tapes 4′ round the roller R′ at 5′ 6′, and thence from the tapes 7′ 8′ round the printing-roller I′ at 9′, by which it is printed on the other side; after which it is carried by 10′, 11′, 12′ to the lower receiving-board B′ at 13′.

The inking-rollers are shown at E P D and D′, and are arranged

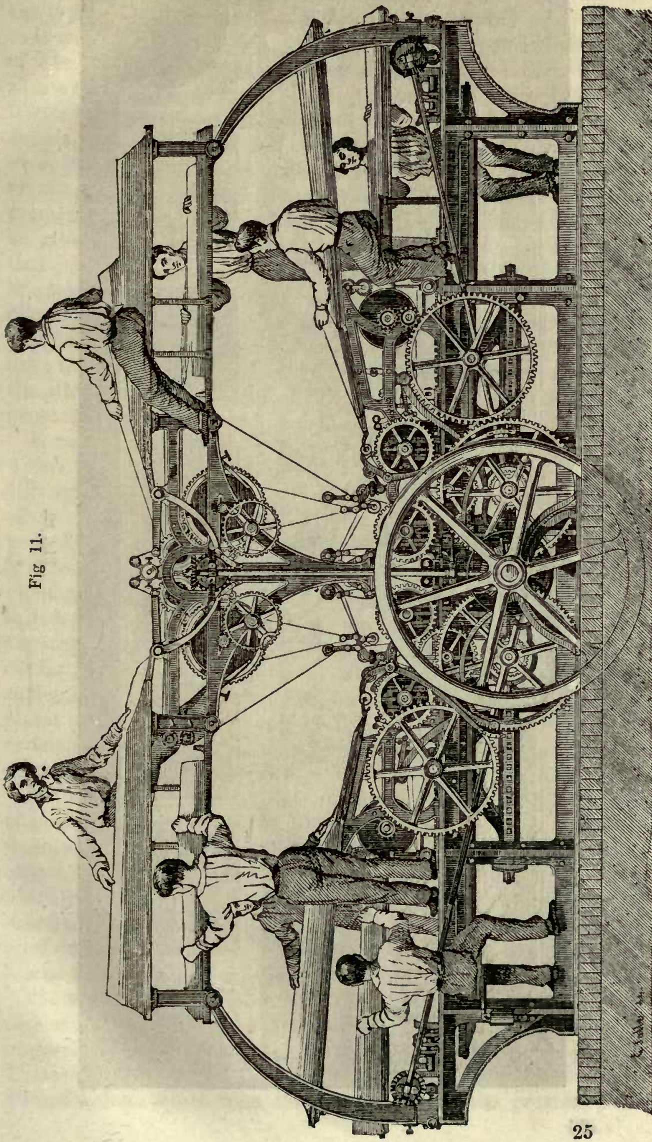


Fig 11.

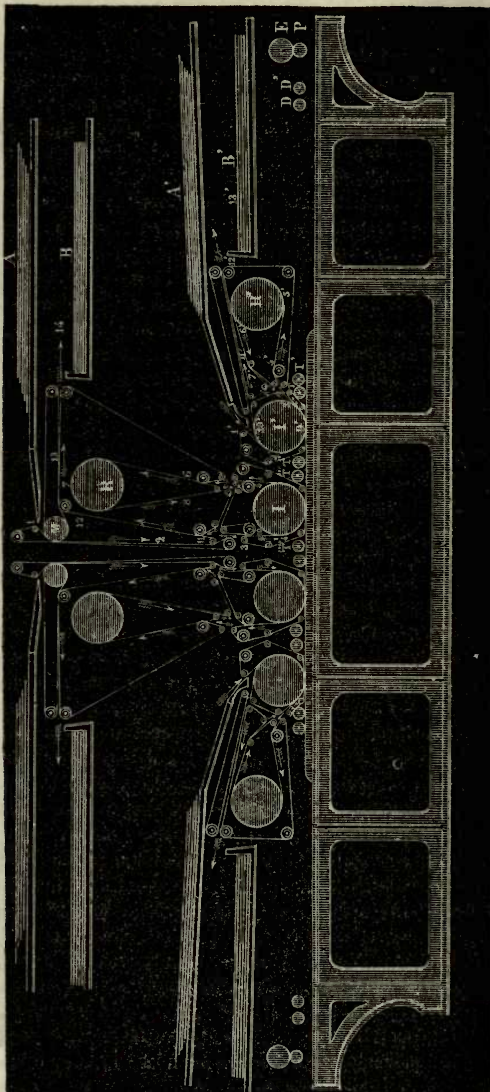


Fig. 12.

in the usual manner, at T, T′, T″, T‴, and T″″, to spread the ink on the types.

It will be perceived that the power of this press is equal to that of *The Times*, the difference being that *The Times* prints 12000 sheets on one side only, while this prints 6000 on both sides. *The Times* machine requires eight layers-on and eight takers-off, being double the number required by Marinoni's press. It must, however, be observed that, in the practical management of newspaper printing, as conducted in *The Times* office, the power of Marinoni's press, though in a certain sense equal to that of *The Times*, would be altogether insufficient; for it is indispensably necessary for that journal to print 60000 copies on one side of the paper during the last five hours of the morning. The matter allotted to the other side of the paper is so selected that it can be composed and printed in the earlier part of the night, or even of the previous day; the pressure falling exclusively on the matter which occupies the other side of the paper, consisting chiefly of the latest intelligence and Parliamentary reports.

It may be asked, therefore, how the journal of *La Presse*, of which the circulation, though inferior to that of *The Times*, is still very large, can be printed with the necessary celerity? The answer is, that *La Presse* does not contain as much as the tenth part of the letter-press of a copy of *The Times*, and that therefore, it is found practicable to compose the matter in type twice or oftener, so as to produce two or more distinct *forms*, as they are called, which are put to work at as many different presses. The expense of composition is further economised at the printing office of *La Presse* by stereotyping the matter, which is composed at a sufficiently early hour to admit of that process, the stereotype plates being melted down the next day. By this expedient double or triple composition is only necessary for the intelligence which comes too late to allow of being stereotyped.

27. **Marinoni's Book-printing Machine.**—A convenient form of printing-engine for books, constructed by the same engineers, is shown in fig. 13, by which, however, the sheets are printed on one side only. The layer-on delivers the sheets upon the board M (fig. 14), from which they pass round the printing roller I, and are discharged as indicated by the arrow upon the receiving-board R. The rollers for delivering and spreading the ink on the types are arranged in the usual way.

28. **Newspapers.**—Of all the applications of printing to the uses of life, that which has conduced most to the advancement and improvement of the art has been the printing of newspapers. These organs of public opinion and intelligence combine the conditions which require from the printing press the greatest con-

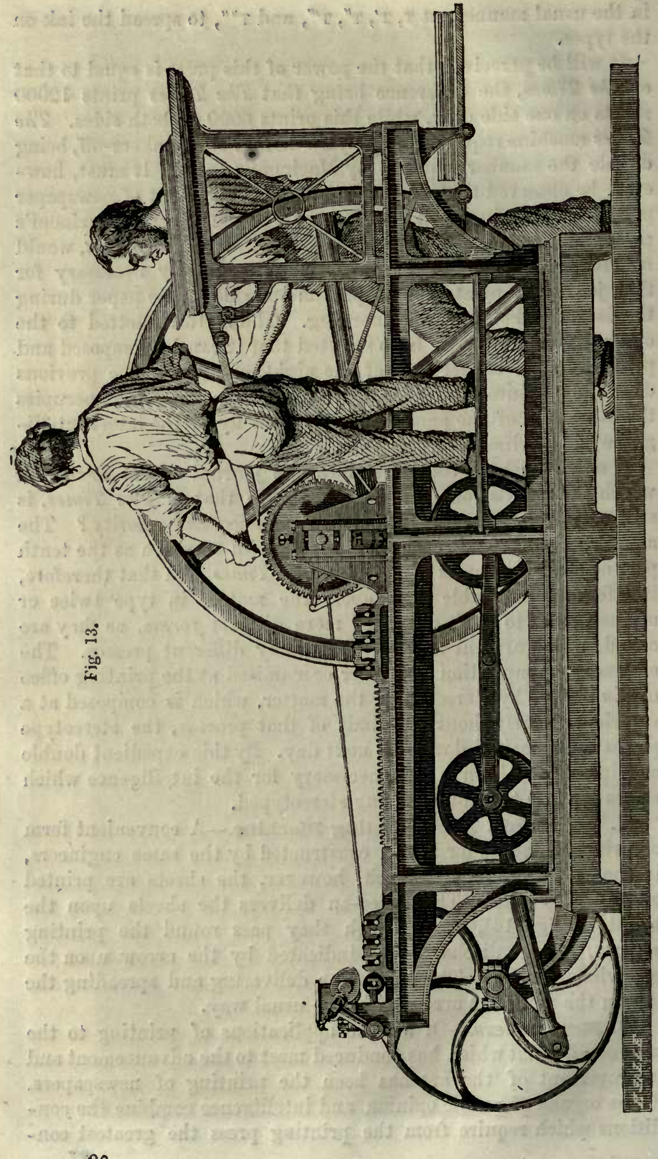
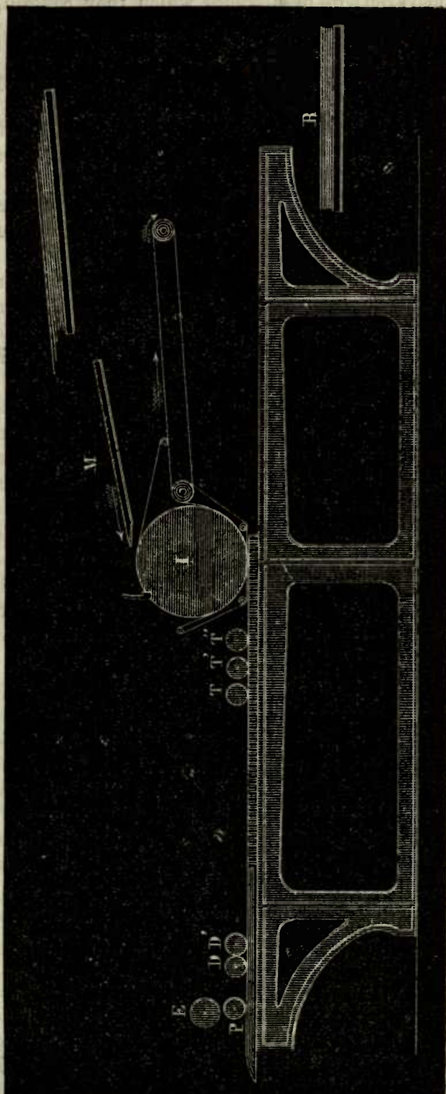


Fig. 13.

Fig. 14.



ceivable degree of perfection. Extreme rapidity of composition combined with the greatest attainable celerity of press-work are above all things indispensable, and how far these objects have been attained by the modern printing-machine, will be understood by what has been stated in the preceding paragraphs. On the other hand the improvement in the machinery of printing, which the exigencies of journalism have thus produced, have themselves reacted on journalism in the most surprising manner, so that the feats of art now accomplished in the establishment of the London daily papers, justly excite the admiration and the wonder of all well-informed persons. These newspapers are remarkable for the vast mass

and variety of intelligence which they contain, the celerity with which they are printed and circulated, and the accuracy and copiousness of the reports which they afford of the proceedings of all public bodies. These results are obtained by an enormous expenditure of money and a minute and judicious division of labour. A corps of able and intelligent reporters is maintained, whose duty it is to attend the Houses of Parliament, the Courts of Law, Police Offices, and all public meetings. These relieve each other at short intervals of from half to three-quarters of an hour, when they return successively to the office of the journal and there write out in long-hand the substance of their short-hand notes. These are immediately delivered over to the compositor, who proceeds to set them up in type, and when a column has thus been composed it is handed over to the reader, after receiving whose correction it is returned to the compositor, who introduces the corrections into the columns of type. A proof being taken it is laid before the editor who decides the part of the paper it is to occupy, and whether it may need alteration or abridgment. It happens thus in the case of long debates, and sometimes in the case of long speeches, that a part will be actually set up in type and printed in proof before the remainder has been yet spoken.

29. **Reporters.**—In appreciating the functions of reporters, it is a great though very common mistake, to suppose that their duty consists merely in reproducing verbally the speeches delivered. If this were to be done no journal, however great its magnitude, would be sufficient to contain even a small fraction of the matter reported. The reports are therefore necessarily abridgments, with the exception of certain passages of striking importance, occurring occasionally in the speeches of the most eminent public men, and these can always be distinguished in the reports by the use of the first person instead of the third. The reporter takes therefore not verbatim notes but merely abridged memoranda of what is said, and as he remains in attendance only for the brief interval of half an hour or a little more, his memory by practice enables him to supply the lacunæ, so that when he arrives at the office of the journal he is enabled to write out a good abridged report of what he has heard. It is in this admirable capacity for judicious abridgment that the skill of the reporter, and more especially of the parliamentary reporter, is shown.

It will easily be understood from what has been here stated, that a well-conducted journal in London is obliged to maintain a large corps of reporters. They are generally classified according to their particular abilities and fitness. The highest class being parliamentary reporters, who are understood to be paid at the rate of about 5*l.* per week during the session of parliament. The law

reporters are a peculiar class requiring special qualifications, and are generally barristers who have not yet obtained sufficient practice to occupy their time. Police reporters form another distinct and peculiar class, who supply that part of the journals to which are consigned the proceedings of the police offices.

In fine, there is another class of agents for the supply of general intelligence, whose business it is to collect information on all subjects in all parts of the town.

30. **The Court Newsman** is not to be overlooked. This personage supplies daily to all the journals, those paragraphs in which are found recorded the movements of the Sovereign and the Royal Family; who was invited to dinner at Windsor or Buckingham Palace; what music was performed at and after dinner, and by what band, and so forth. The same functionary is entrusted to supply accounts of the various parties and entertainments given by the aristocracy.

31. **Foreign Correspondents.**—Among the staff of daily London journals the foreign correspondent holds a conspicuous place. The principal journals maintain such a correspondent in all the principal foreign capitals, and, in case of war, such a correspondent accompanies the army and the fleet. The foreign correspondents maintained in the principal European capitals usually keep bureaux, and have assistants, who collect news and supply reports. A despatch is forwarded to London always once, and often twice, a day, the telegraph being resorted to when news of considerable importance is required to be transmitted with more promptitude.

32. The rapidity with which the circulation in newspapers has increased in the United Kingdom during the last century, but more especially during the latter half of it, may be judged from the following facts.

In the annexed table is given the total number of newspapers circulated in this country during the years expressed in the first column:—

Years.	Number circulated.	Average annual increase.
1751	7,412575	
1801	16,085085	173450
1821	24,862186	438855
1831	35,198160	1,033597
1841	59,936897	2,473873
1849	78,792934	2,357005

Thus it appears, that while the average annual increase of the circulation of journals, in the latter half of the last century,

was limited to 173000, the average increase during the first twenty years of the present century was 439000; the next ten years this rate of increase was more than doubled, and in the succeeding period it was augmented in a sixfold ratio. The total circulation in 1849 was more than ten times the circulation in 1751.

By comparing the circulation of journals with the population, an estimate may be obtained, if not of the diffusion of knowledge in general, at least of that description of information of which journalism is the vehicle. In the following table are given the amount of the population at the epochs above mentioned, and the number of journals circulated per head of the population.

Years.	Population.	Number of journals per head.
1751	6,377574	1·1
1801	10,942646	1·5
1821	14,391631	1·7
1831	16,539318	2·1
1841	18,720394	3·2

Thus, relatively to the population, the circulation of journals had increased in a twofold proportion in 1841, as compared with 1821, and in a threefold ratio as compared with 1751. Taking the population of Great Britain in round numbers in 1849, the ratio of journals to the populations would be 4 to 1, being an increase in the same ratio on the circulation in 1751.

So far, therefore, as the circulation of journals can be regarded as an exponent of the diffusion of knowledge, a greater amount of general information prevails now than prevailed a century ago in a fourfold proportion.

Since the dates of these returns, a vast change has been made in the circulation of journals, by the abolition of the newspaper stamp and reduction of the advertisement duty. Before the abolition of the stamp, the amount of the daily circulation of each journal was known by the Stamp-office returns. The average daily circulation of *The Times* was then about 40000, or about double the aggregate circulation of all the other morning journals. Since the abolition of the stamp duty, and the consequent reduction of the price of the journals, a considerable increase of circulation has taken place as well in *The Times* as in the other journals, and we shall not perhaps overrate the present circulation of the London morning newspapers if we put them down in the aggregate at 100000.

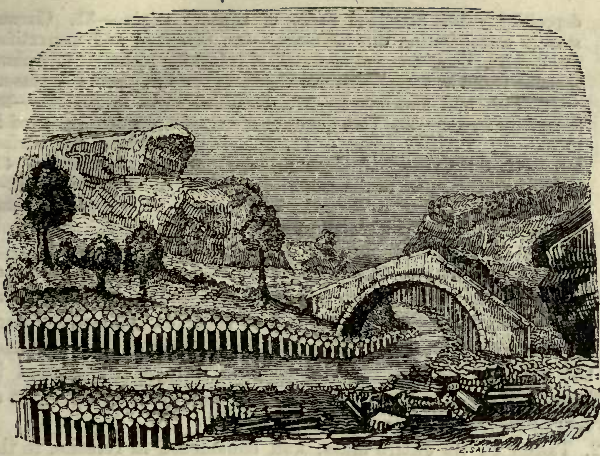


Fig. 31.—BASALTIC CAUSEWAY OF THE RIVER VOLANT. (DEP. ARDECHE, FRANCE.)

THE CRUST OF THE EARTH;

OR, FIRST NOTIONS OF GEOLOGY.

CHAPTER I.

1. The earth, a subject of long-continued observation and investigation.—2. Mathematical geography.—3. Physical geography.—4. Phenomena of the oceans and seas included in it.—5. Hydrology, meteorology, and climatology.—6. Political geography. — 7. General subject of geography.—8. Geology.—9. Original fluidity of the earth inferred from its spheroidal form.—10. This form ascertained by observation and measurement.—11. The solid crust was formed while the earth was in a state of rotation.—12. Increase of temperature from surface downwards.—13. Within the crust the earth still in a state of fusion.—14. Subject of geology.—15. How the structure of the crust to a great depth is rendered manifest.—16. Section of the crust where no disturbance has taken place—strata occur in a fixed order.—17. Rocks in their geological sense.—18. Their classification in five principal divisions.—19. Lowest bed, being the foundation of the crust, consists of igneous rocks produced by the superficial cooling of the molten materials of the globe.—20. Materials of which the igneous rocks are formed.—21. Constituents of granite, feldspar, mica, quartz.—22. These components of igneous rocks agglomerated mechanically.—23. But the components themselves are chemical compounds. — 24. Varieties of granite—porphyry.—25. Gneiss.—26. Secondary rocks.—27. Transition or metamorphic rocks.—28. Stratification.—29. Produced by aqueous

deposition.—30. Stratified rocks of aqueous origin.—31. Circumstances corroborating this inference.—32. Stratified and unstratified rocks.—33. Condition and materials of transition rocks.—34. Animal remains found in them.—35. No vegetable remains—probable reason. —36. Fish and annelidans.—37. Stratified rocks in general.—38. Secondary rocks.—39. Vast quantity of organic remains deposited in them.—40. Tertiary rocks. — 41. Diluvium, alluvium, and surface soil.—42. Subdivision of these principal groups of strata. — 43. General inference as to the condition and ages of stratified rocks.— 44. They constitute a chronological scale. — 45. Complexity and defects of geological nomenclature.

1. It cannot be matter of surprise that of all the great bodies of the universe the earth, which has been assigned by the Creator as the habitation of the human race, has received the largest share of attention on the part of those who have devoted their faculties to the observation and investigation of nature. Regarded in different points of view it has formed the exclusive subject of several branches of science.

2. Taken in its entire mass, and considered in relation to the other bodies of the solar system, it constitutes the subject of MATHEMATICAL GEOGRAPHY, which includes the solution of such problems as the determination of the magnitude of the earth—its exact form—its relation to the other bodies of the solar system —its annual motion round the sun which produces the apparent movement of that luminary through the signs of the Zodiac—its diurnal rotation which produces those apparent motions of the firmament which cause the vicissitudes of day and night—the peculiar position of its axis which produces the succession of seasons—the division of the globe into zones and climates, and the system of imaginary circles of latitude and longitude which supply the means of expressing the position of all places on the globe, relatively to each other, and to the equator and poles.

3. The earth, viewed in regard to the various physical states of its surface, constitutes the subject of PHYSICAL GEOGRAPHY, which includes a description of the distribution of land and water—the extent and configuration of continents and islands—the elevation and prevailing direction of mountain chains—the form, extent, and direction of plains and valleys—the general altitude of the surface of the land above the common level of the sea—the effects of soil and climate, and the local distribution of animal and vegetable productions.

4. This division of geographical science also includes the various phenomena of the ocean and seas, their depth, saltness, and temperature, the prevailing direction and velocity of ocean currents, the extent of the polar ice and circumstances incidental to it.

5. The subdivisions of physical geography are sometimes denominated HYDROLOGY, which includes all that relates to the ocean and seas; METEOROLOGY, which includes the investigation of atmospheric phenomena; and CLIMATOLOGY, which involves the consideration of the mean temperature of different countries, the altitude of the line above which there is perpetual snow, the prevailing winds, the barometric pressure, the annual quantity of rain, and so on.

6. The earth, considered as the abode of mankind, distributed into different nations and placed under different forms of government, constitutes the subject of POLITICAL GEOGRAPHY, which therefore includes the consideration of the moral and social condition of different peoples, their language, religion, forms of government, and civilisation, and the population, resources and local relations of different countries.

7. It appears, therefore, that these several divisions of geographical science are limited to the appearances and phenomena developed upon the surface of the earth, in the waters which partially cover it, and in the atmosphere by which it is surrounded.

8. Another, and not less important department of science concerning the earth, relates to the condition and structure of those parts of the globe which lie between its surface and its centre, and which constitute the subject of GEOLOGY.

9. In mathematical geography and astronomy, certain physical circumstances attending the interior of the earth have been developed. Thus it is proved that the density of the globe gradually increases from the surface to the centre; and from its peculiar form it is inferred that, at the epoch of its formation, the materials composing it must have been in a fluid state. It has been already shown in our Tract on the "Earth," that the form of the globe is what in geometry is called an *oblate spheroid*, a figure somewhat resembling an orange or a turnip. By reason of this figure, the earth is flattened at the poles and bulged out at the equator. Now it is proved in mathematical physics that if a fluid globe have a motion of rotation on one of its diameters as an axis, the centrifugal force of the matter composing it will cause it to bulge out at the equator and to flatten at the poles, so that all sections of it made by planes passing through the axis are ellipses, and the degree of the elliptic form of these sections will be so much the greater as the velocity of rotation is more rapid; and so closely connected is this degree of ellipticity with the velocity of rotation, that mathematicians are able to assign the exact form of the elliptic section which must correspond to each particular velocity of rotation.

10. Before the exact form of the earth had been determined by

direct observation and measurement, mathematicians had already ascertained by computation what ought to be its form consequent upon its rotation upon its polar axis, and the time in which it is actually known to rotate, and the result of their computations was afterwards found to agree with the utmost possible numerical precision with the actual form which the earth was proved to have by immediate observation and measurement.

11. It is therefore inferred from this that the earth, in its original state, and before it assumed its present condition, was a fluid mass, and that while in this fluid state, it received the diurnal rotation by which it is now affected, and which produces the vicissitudes of day and night. It was, therefore, after having assumed this spheroidal form, that its superficial parts hardened and solidified, and after undergoing a certain succession of changes assumed their present condition.

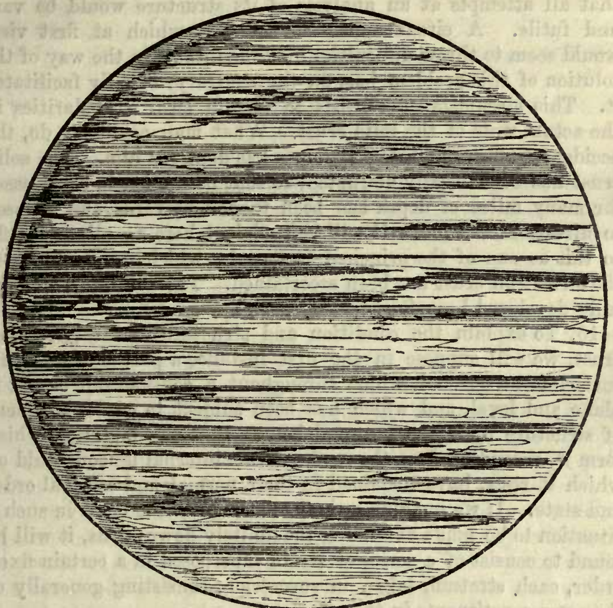
12. It has been also shown in our Tracts on "Terrestrial Heat," and on "Earthquakes and Volcanoes," that when we penetrate into the crust of the earth by mines, boring, or other artificial means, the temperature is found to undergo a gradual and regular augmentation, and this augmentation being continuous, so far as direct observation has been carried, may be assumed by analogy to increase to a still greater depth in the same proportion—a conclusion which also is verified by the phenomenon of hot springs rising from a considerable depth, and by various volcanic effects. Assuming this gradual increase of temperature to go on indefinitely in descending towards the centre, it has been shown that at a certain depth the temperature must be such that even the most refractory constituents of the globe would be reduced by it to a state of fusion.

13. The increase of temperature being at the rate of about a hundred thermometric degrees per mile, it would follow that at the depth of about 40 miles, or about the 100th part of the entire distance from the surface to the centre, we should arrive at a temperature of 4000°, at which it is quite certain that no part of the matter composing the earth could remain solid. It is therefore inferred, without the necessity for extreme numerical precision, that the earth is a spherical shell, the superficial part only being solid—all the central part being in a state of igneous fusion—the thickness of the solid crust being, as just stated, about the 200th part of the entire diameter. A section of it would be such as is represented in fig. 1.

If, therefore, as we have already stated in our Tract on "Earthquakes and Volcanoes," the egg of a fowl be imagined to represent the earth, its shell would be much too thick to represent its solid crust.

It is no rhetorical exaggeration that the globe we live on is a stupendous, but very thin spherical shell, charged with liquid fire; and if such be the case it may naturally be asked how it happens, that so thin a crust supported on a fluid so mobile can maintain that

Fig. 1.



general state of stability which characterises it so strongly, that it is referred to in times ancient and modern as the type of all that is most solid and most durable. An answer to this reasonable question will be collected from all we shall have to explain in the present Tract.*

14. The investigation of the structure and condition of this solid crust of the terrestrial spheroid, extending from the fluid

* According to Mr. Hopkins, the thickness of the crust is subject to much local variation, being very unequal on its inner surface. He considers that it is probably cavernous, and that masses of fluid mineral matter may be distributed through its cavities. According to him the thickness in some parts may be as great as 800 or 1000 miles. See Memoirs on the State of the Interior of the Earth, in the Philosophical Transactions from 1839 to 1842.

nucleus upon which it is supported to the surface, constitutes the subject of geology.

15. Considering that however thin may be the crust of the earth as compared with its diameter, its absolute thickness being at least from 30 to 40 miles, and that this very far exceeds any depth which is accessible to direct observation, it might be imagined that all attempts at an analysis of its structure would be vain and futile. A circumstance nevertheless which at first view would seem to throw difficulties insurmountable in the way of the solution of this problem has, on the contrary, happily facilitated it. This circumstance consists in certain local irregularities in the actual state of the solid crust. What man could not do, the accidental effects of internal forces has done for him. The solid crust has been locally disrupted, so that its section in some cases for many miles of depth has been turned upwards and exposed to direct observation. It will be sufficient here to allude briefly to this as one of the principal means, by which the structure of the terrestrial crust has been ascertained. The point will be more fully developed hereafter.

16. To explain the condition and structure of the terrestrial crust, we will suppose in the first instance a part of the earth's surface to be selected, which throughout a considerable extent is plane and level, and which has been subject to no derangement of structure by internal convulsion, so that the materials which form it, extending from the surface to the internal igneous fluid on which it rests, have remained in their normal and original order and state. If we imagine a vertical section of the crust in such a situation to be made extending indefinitely downwards, it will be found to consist of a series of strata superposed in a certain fixed order, each stratum, taken in succession, consisting generally of the same constituents in the same state.

17. The matter composing these strata is called by geologists ROCKS, a term used in this science in a sense somewhat different from its common popular signification. ROCKS in the geological sense does not necessarily imply masses of stone. It signifies any agglomeration whatever of matter which may be found to enter into the composition of the crust of the earth. In this sense clay and sand come under the name of ROCKS as well as granite and marble.

18. Taking then the term rocks in this extended sense, the successive strata composing the shell of the earth is found to consist of different layers of rock, each layer being characterised by rocks existing in a peculiar state of aggregation.

The strata thus superposed, and extending from the fundamental layer which rests immediately upon the matter in igneous

fusion within the terrestrial shell upwards to the surface, are very numerous.

They have, however, been reduced to the five following classes proceeding upwards.

1° The igneous rocks.

2° The transition or metamorphic rocks.

3° The secondary rocks.

4° The tertiary rocks.

5° The diluvial and alluvial layers of matter upon which the superficial soil is spread.

We shall first briefly notice these five great layers, each of which, however, as will hereafter appear, consists of numerous subordinate courses or strata.

19. The lowest or fundamental layer, called igneous rocks, consists exclusively of agglomerations of mineral masses in a state of crystallisation. This is the condition which matter would necessarily assume, and which it could only acquire by having been gradually cooled and solidified, after being brought to a state of fusion by a great elevation of temperature. Under such circumstances its chemical constituents would group themselves according to their mutual affinities, and would assume the various crystallised forms proper to them. After cooling and solidifying, the materials would present the appearance of an agglomeration of crystals thrown arbitrarily together and without regularity or order. Now this being exactly the appearance presented by the rocks which form the foundation of the crust of the globe, it is inferred that they were originally in a state of igneous fusion, and that by the gradual loss of heat by radiation, they were superficially cooled and solidified. The parts of the primitive rocks which have been brought under the observation of geologists are considered as forming the external parts of this solid layer.

These rocks are from circumstances here explained often denominated PLUTONIC OF IGNEOUS ROCKS, OF ROCKS OF IGNEOUS ORIGIN.

20. Those primitive layers, which may be regarded as the original materials of which the entire crust of the globe is formed, consist chiefly of that rock familiar to all observers of mountainous countries called GRANITE, the most imperishable of all stones, and therefore the most precious for the purposes of construction. This granite is mixed in the fundamental layer in smaller proportions with the minerals called AMPHIBOLE, PYROXENE, and PERIDOTE.

21. Granite is an agglomeration of the crystals of three minerals, called FELDSPAR, MICA, and QUARTZ. Feldspar is the soft grey part of the granite, which is easily scratched. The

oxides of iron and manganese are occasionally mixed with this constituent of granite, and though present in extremely minute quantity, produce nevertheless a very striking appearance, rendering the rock white, cream-coloured, or red, according to their varying proportions.

MICA is the shining glossy particles of the stone, which reflect light like bits of glass or metal. The name is derived from "MICANS," *glittering.* Mica may be seen in many other stones, as also in sand.

QUARTZ, which appears in granite in the form of white crystals, is the substance known as SILEX or SILICA, or the EARTH OF FLINTS, and is one of the hardest and most abundant of mineral substances, entering largely into the composition of many other mineral masses. It is from this constituent, chiefly, that granite receives its hardness.

Silica is familiarly known as ROCK CRYSTAL.

22. It must be remembered that the several materials of which the igneous rocks are thus composed, are not combined together chemically. They are not combined for example in the same manner as are sulphur and oxygen, when these constituents produce vitriol. They are on the contrary merely agglomerated and brought into mechanical juxtaposition, forming a solid mass by the mere cohesion of crystal to crystal, so that by the action of mechanical force it would be possible to resolve the rock into its component parts.

23. Each of these constituents is, however, itself a compound. Thus feldspar is a compound of the silicates of several chemical substances, such as alumina, lime, and potash, or soda—that is, it is a combination of these severally with silicic acid.

Mica is composed of like silicates, with the addition of silicate of iron.

Quartz is in fact silicic acid itself. It will appear, then, from this statement, how important a part silex, or earth of flints, plays in the formation of the globe.

24. If the constituents of the igneous rocks were combined, one with another, chemically, instead of being mechanically juxta-posed, they would, according to a general law of nature, always be found to prevail in the same rocks in one invariable numerical proportion; but being, as explained above, merely agglomerated by cohesion, without any chemical union, they may exist in any proportion whatever, and hence have arisen a corresponding variety of granites. In some specimens the quartz and mica are altogether absent, and then the granite, consisting of feldspar only, in the pasty and crystallised state, takes the name of PORPHYRY.

In other specimens, the proportion of feldspar being large, and that of mica and quartz small, the rock is called PORPHYROUS GRANITE.

25. In general, the little laminæ of mica are distributed irregularly through the granite, their faces being turned in all conceivable directions. In certain specimens, however, they are observed to be placed parallel to each other, so as to give the rock a lamellated, slaty, or schistous texture. The granite, in such cases, takes the name of GNEISS, from the Danish "*gnister.*"

26. Having thus briefly described the composition and condition of the fundamental layer of matter, upon which the solid shell of the earth is based, and indicated the circumstances and characters which are evidence of its igneous origin, we shall now proceed to explain the condition and character of the superincumbent strata, which, as will presently appear, have had an origin of a very different kind, and dates of incomparably more recent formation.

27. The strata which rest immediately upon the igneous rocks have been denominated TRANSITION or METAMORPHIC, inasmuch as they partake partly of the character of the igneous rocks, and partly of that of the rocks incumbent upon them. They partake, in certain instances, of so much of the former and so little of the latter, that in the earlier epochs of geological research, they were classed with the igneous rocks, from which, nevertheless, they are distinguished by sufficiently evident marks of incipient stratification.

28. It has been explained that the materials composing the igneous rocks are confusedly and irregularly agglomerated without the least appearance of even an approach to any regularity of structure, and it has been shown, that this is at once the consequence and evidence of their igneous origin. Such, however, is not the character of the superincumbent rocks. The materials of which these are severally composed are found to be distributed, one over another, in regular layers, bounded by parallel and horizontal surfaces, resembling the courses of masonry. Now such a distribution never could have resulted if these, like the primary rocks, had, previously to their formation, been in a state of fusion.

29. Such an arrangement, on the other hand, is precisely that which would ensue, if the materials, composing the strata, having been mixed with, and suspended in water, had, after the fluid became tranquil, gradually subsided and settled at the bottom. In such a case, the matter thus subsiding would be deposited in a regular series of layers, one above the other, with level and parallel surfaces. The lowest layer would be composed of the heaviest part of the matter held in suspension by the water, that

being the most prompt to sink. Next would come layers of less ponderous matter, and then another lighter still, and thus layer upon layer would be deposited until the whole of the suspended matter would have subsided.

If from any cause after this subsidence the water retired, the ground forming its bottom would be left bare, and the dry land would, if it were excavated, be found to consist of the succession of strata here described.

Now if the actual layers composing the successive strata, which are superincumbent on the igneous rocks, did really in their origin proceed from such a cause, it might be expected that they would succeed each other in the order here indicated, those most apt to subside holding the lower position, and such accordingly is found to be the case.

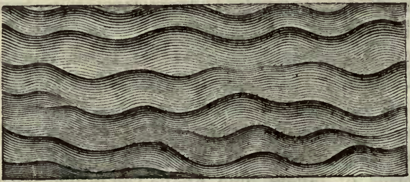
30. In accordance with these results of observation on the strata forming the crust of the earth, and with concurrent evidence deduced from other appearances, it has been inferred, with a degree of probability amounting to moral certainty, that the stratification has resulted from such a series of physical causes as those above described. Each stratum consisting of a series of parallel layers is assumed to have been a sedimentary deposit precipitated from water, by which the surface of the solid part of the globe has been at former epochs covered, and that these waters having become quiescent before retiring, the matter suspended in them was deposited in layers having more or less regularity, their surfaces being parallel and level, or nearly so.

31. Among the many collateral circumstances which corroborate these conclusions may be mentioned two.

First, the frequent occurrence in the bounding surface of the layers of the form of the ripple of water, as it is observed in the sands of the sea shore after the fall of the tide has laid them bare.

An example of such traces left upon the beds of carboniferous limestone and Portland-stone, in the neighbourhood of Boulogne, is shown in fig. 2.

Fig. 2.



Secondly, by the remains of various aquatic animals and plants, which are often preserved in their natural position, in

which they were tranquilly buried by the matter deposited upon them. Numerous remains of crustacea and mollusca are thus found in perfect preservation in strata situate at great distances from the shores of the sea, figs. 3, 4.

Fig. 3.

Fig. 4.

These phenomena will be more fully explained hereafter.

32. These circumstances establish a marked distinction between the igneous and the superincumbent rocks. The latter, consisting of matter distributed in regular and horizontal layers are called STRATIFIED ROCKS, while the former consisting of materials agglomerated without any semblance of order are called UNSTRATIFIED ROCKS.

As the unstratified rocks are called PLUTONIC or IGNEOUS ROCKS, the stratified are denominated NEPTUNIAN or SEDIMENTARY ROCKS, and sometimes ROCKS OF AQUEOUS ORIGIN.

33. The transition or metamorphic rocks, which rest upon the igneous rocks, show traces of stratification combined with such partial crystallisation as may be inferred to have arisen from their contact with the highly heated surface of the rocks below them. The principal rocks composing the transition-system, are the gneiss, already described, crystallised limestone, quartz, hornblend, thick layers of the rock called the old-red sandstone, and many varieties of slate and shale.

34. Independent of the existence of distinct stratification in these, they are still more decidedly distinguished from those of igneous origin by the deposits of animal remains found in them, which, though neither numerous nor of a high order of organisation, are nevertheless present in sufficient quantity to put aside in the most conclusive manner all other suppositions, than that of sedimentary formation and aqueous origin.

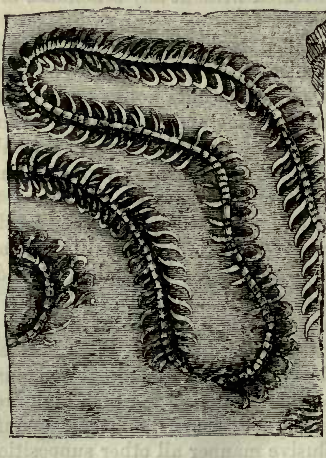
35. It has been assumed by many geologists, that although

animal remains have been found in these transition-rocks, no traces of vegetables were discovered there, from which it was inferred that the existence of animal life upon the globe preceded that of vegetation. M. d'Orbigny has shown, however, that such is not the case. The remains of various marine plants have been found by Mr. Hall in the lower Silurian strata in the State of New York. The coal-mines of Vallongo, in Portugal, are in the same strata; and the richest coal deposits of Spain are in the Devonian formation. It must, therefore, be considered that animal and vegetable life were always co-existent, as indeed is apparent, *à priori*, inasmuch as animals which do not feed on each other must necessarily feed on vegetables.

Organic remains of animals have been found in the superior layers of transition-rocks, which present singular interest as being the earliest examples of life traceable in the growth of the earth. It would seem, that after the external parts of the igneous matter had been hardened by the process of cooling, the first sedimentary layers deposited upon it became the habitation of certain races of organised beings.

36. Among these the researches and observations of Professor Phillips have brought to light various species of small fish, and there have been found, near Llampeter in North Wales, in the same strata, traces of a species which the late Mr. William Macleay, a profound

Fig. 5.



naturalist, pronounced to be a sea-worm of the class of Annelidans, being the first in Cuvier's classification of articulated animals.

The remains of one of these sea-worms, *Nereites Cambrensis*, found at Llampeter, is shown in fig. 5. The body of this creature consisted of about 120 joints.

37. In fine, then, we find that upon the igneous rocks as a foundation the superficial structure of the earth has been erected, consisting of a series of layers or courses of natural masonry, one placed above another—the formation of each of which has been the work of countless ages; that transition-rocks were the first and earliest of these, while those which form the surface of the earth, and are the habitation of the existing organised tribes, were the last; and that the epoch at which these latter tribes, including the human race, were called into existence, remote as it must appear, compared with all measures of time familiar to us, is recent when referred to that system of chronology which is written upon the crust of the globe.

38. Above the transition-rocks, which, as we have stated, were first placed in the class of primitive rocks, succeed a series of layers which have been denominated SECONDARY ROCKS. These consist chiefly of chalk, clay, argillaceous slate, shale, red and brown sandstone, limestone, iron and lead ore, and coal. They abound in organic remains, animal and vegetable, in a high state of preservation, the minutest parts being often perfectly observable.

39. The extent to which the earth was the theatre of organic life, at the epochs of the deposition of these numerous strata, may be conceived when it is stated that, in 1834, a German naturalist and geologist counted no less than 9000 species, the remains of which, at that date, had been found below the superior limits of the stratified rocks, not one of which has ever existed since the earth became the habitation of man.

Among the animal remains which abound in these secondary strata may be mentioned corals, crinoides, mussels, trilobites, fishes, reptiles, insects, marine and fresh-water shells, sponges, and animalcules countless in number.

Of the reptiles, the most remarkable are various species of lizard-shaped animals, constructed on a scale of colossal magnitude, called Saurians, from the Greek word *Σαυρος* (Sauros), lizard. These have been variously denominated megalosaurus, plesiosaurus, ichthyosaurus, and so on.

40. Upon the secondary rocks repose a series of strata of more recent deposition, called on that account TERTIARY ROCKS. These consist of a thick bed of clay, limestone, sand, pebbles, and white sandstone. They abound in organic remains, which are distinguished from those of the lower and more ancient strata by including a considerable proportion of the still living species. Thus the lowest strata of the tertiary rocks contained 5 per cent.,

and the superior strata 10 per cent. of the species found among the animal tribes which still continue upon the earth.

41. In fine, superposed upon these tertiary are several layers of earthy matter, upon which the actual organised world is placed. These are usually resolved into two beds, the lower of which, denominated DILUVIAL, consists of deposits of gravel and clay, with boulder-stones, rounded in different degrees by attrition, giving indication of having been carried from a distance by the *extraordinary* action of water, from which the general name DRIFT has been given to them.

The superior bed consists of sand, clay, and gravel, upon which the surface soil, which is the theatre of agriculture, rests. This consists of decayed and decomposed vegetable matter, mixed with more or less of the disintegrated matter of the inferior beds. This uppermost layer is produced chiefly by the *ordinary* action of water, and is denominated ALLUVIAL.

42. Such are the five principal groups of rocks, into which geologists have divided the matter which forms the shell of the globe. The transition, secondary, and tertiary groups, have each been subdivided into several layers or strata, each of which is distinguished by the peculiar sorts of mineral matter of which it is composed, and the peculiar species of organic remains which it contains. Geologists, however, are not agreed either as to the limits of the five principal groups, or as to their distribution into subordinate strata. Thus they are not agreed as to where each of the principal groups ends and the next begins. The rocks, which one calls *primitive*, another denominates *transition* or *metamorphic*. Those which one assigns to the upper part of the transition-system, another assigns to the lower part of the secondary system; and in like manner what one assigns as the highest strata of the secondary, another gives as the lowest strata of the tertiary. These discrepancies, however, arise more from the nature of the things than from any deficiency of our knowledge of them. Between one group and another there is no essential distinction, and their classification into primary, secondary, and tertiary, though convenient, is, like many other classifications, to a certain extent arbitrary.

43. From what has been stated, respecting the strata constituting the crust of the earth, the following consequences will follow:—

First. The unstratified and igneous rocks existed prior to the stratified or sedimentary rocks.

Secondly. The stratified or sedimentary rocks were produced in the chronological order in which they are found superposed, the most ancient being the transition-system, and the others being formed in the order of time in which they are superposed,

the oldest being the lowest strata of the secondary, and the most modern the upper strata of the tertiary; the intermediate strata have intermediate dates in the order of their superposition.

Thirdly. The sedimentary strata in their original and natural position were necessarily *level;* their bounding surfaces were horizontal and parallel. Wherever, then, they may be found in any other position, it must be assumed that they have undergone derangement of position by some disturbing cause *since their original deposition*. This derangement may arise either from the strata being heaved upwards by a pressure from below, or by their sinking downwards by their incumbent weight forcing them into some inferior vacuity.

Fourthly. Although the succession of strata constituting the series, from the primitive rocks upwards to the surface, is by no means invariable, and is subject on the contrary to many local variations, still its general character is such as has been described. If the sedimentary strata, proceeding from the lowest upwards, when complete, be expressed by the letters A, B, C, D, &c., it will sometimes happen, from local causes, that the actual series may be A, B, C, E, &c., or A, B, D, E, &c., or A, D, E, &c., but it can never happen that the series shall be D, B, A, C, &c. In a word, one or more strata of the series may be wanting, but their natural order is never inverted.

44. It appears, therefore, that the character and order of the sedimentary strata constitute a chronological scale indicative of the history of their formation. It is true that the value of the unit of this scale is not and cannot be known, inasmuch as the absolute intervals of time, necessary for the deposition of the strata severally, cannot be certainly determined. This, however, does not prevent the geologist from pronouncing with perfect certainty upon the *order* of time of their deposition respectively.

45. Although the series of strata above described have been deposited, subject to so many local disturbing causes, that there is probably no point on the entire surface of the globe, where a section would exhibit them complete, still by a careful and judicious comparison of observations, made in different localities, their normal arrangement and natural order of superposition has been ascertained, and geologists have grouped and classified them under a great variety of denominations. Owing to the absence of any general convention, no single system of nomenclature has been adopted, as has been so happily effected in chemistry, and though in a less degree, also in zoology. The consequence is that geology is overlaid with a complicated, confused, and discordant nomenclature, detrimental to the diffusion and even to the progress and extension of the science. Those

who desire to obtain even the most superficial acquaintance with it, are therefore compelled to familiarise themselves with a mass of most repulsive technicalities, in which the same thing is called by many different names, according to the varying views, tastes, and even personal caprices of the geological investigators who have devoted their labours to the researches in which it finds a place.

Names have been given to strata or groups of strata in some cases from the localities in which they are found at the surface, as for example the Jurassic, the Silurian, the Cambrian, and the Devonian groups. In other cases, names are derived from the prevalent materials constituting them, as the cretaceous, oolitic, and carboniferous groups. Other names have been adopted from the order of the deposits, as for example eocene, miocene, pleiocene, and pleistocene, from Greek words signifying the first dawn, or the earliest, less recent, more recent, and most recent.

Another set of names has been taken from the presence, absence, or dates of the forms of life exhibited by the organic remains found in the strata. Thus the strata, which are destitute of all such remains, are called AZOIC, from a Greek compound implying the absence of life. The term cainozoic is applied to the most recent strata, including organic remains, mesozoic to the middle strata, palæozoic to the ancient strata, protozoic to the first in which life appears, and hypozoic to those strata which lie below the range of all organic remains.

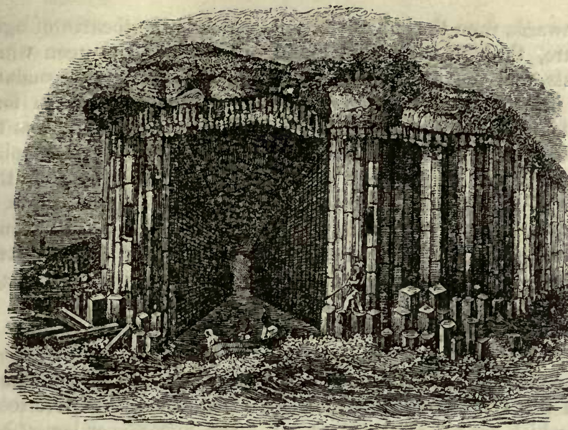


Fig. 37.—CAVE OF FINGAL, STAFFA.

THE CRUST OF THE EARTH;

OR, FIRST NOTIONS OF GEOLOGY.

CHAPTER II.

46. General section of the terrestrial crust tabulated.—47. Approximate thickness of strata.—48. Probable time necessary for their deposition.—49. Recapitulation of the physical history of the globe.—50. Deposition of organic forms.—51. Alternate elevation and depression of the crust.—52. The strata are botanical and zoological museums of past creations.—53. The gradual increase of forms of life.—54. Creative power has always operated on the same general plan.—55. But has varied from period to period in details.—56. Animals created gradually; the more perfect being the more recent.—57. Tabular view of the progress of the animalisation of the earth.—58. Great increase of vertebrates in the tertiary period—No human fossil—Man characteristic of the present period.—59. Temporary existence of certain extinct genera and species.—60. Geological use of characteristic genera and species.—61. Examples—Trilobites characteristic of the Silurian strata.—62. Description of them.—63. Dr. Buckland's reflections on them.—64. Species characteristic of the lias—Ichthyosaurus.—65. Characteristics of the Wealden—Hylæosaurus—Iguanodon.—66. Characteristics of the chalk.—67. Ammonites, their distribution between the Silurian and chalk.—68. Fossil cephalopodes—Nautilus—Danians.—69. Fossil gasteropodes—Bigranulosa murchisonia—Cypræa elegans—Voluta elongata—Pterocera oceani.

46. A GENERAL idea of the series of stratified rocks, proceeding

downwards from the superficial soil, which is the theatre of agriculture, through the alluvial and diluvial deposits upon which it rests, and thence successively through the tertiary, secondary, and primary stratified rocks to the igneous ones which form the foundation of the terrestrial crust, may be formed from the following tabular statement (page 51), which we have compiled from the works of different geologists, and principally from that of Sir H. de la Beche, representing the order of the strata in Western Europe, and which in its general character will be found to correspond sufficiently with the condition of the terrestrial crust in most parts of the world, especially as regards its major divisions.

The strata, which in this table are denominated primary or palæozoic, are by some geologists included under the general denomination of secondary rocks. These must not be confounded with the igneous rocks, which are often called primitive rocks, and which are not stratified at all. The hypozoic or lowest beds of stratified rocks, together with the lower groups of the primary or palæozoic, are those which in the preceding paragraphs have been denominated transition or metamorphic rocks.

47. On contemplating the table, and on considering the peculiar super-structure which it exhibits, combined with the fact that each layer being a sedimentary deposit, must have been the result of an interval of time of considerable duration, two questions will naturally suggest themselves.

What are the dimensions of these several strata, and what the total thickness of the whole structure from the granite foundation on which it rests to the vegetable soil upon the surface, and what has been the probable interval of time required to produce each stratum.

Although certain and definite answers cannot be given to these questions, some degree of approximation may be made to them. The thickness of the several strata and groups of strata is subject to considerable local variation, nevertheless the indications of the limits of these variations in certain parts of the earth, which have been subject to geological survey of more or less accuracy may be useful.

Thus, the following are the estimated thicknesses of several strata, proceeding upwards from the transition-system to the surface in Great Britain.

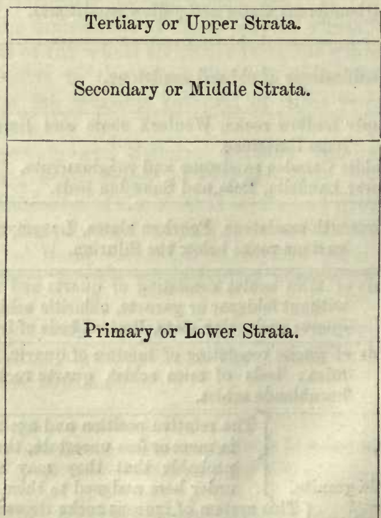
Gneiss system—a few miles.
Mica schist system—from a few yards to a few miles.
Cambrian system from one to five miles.

Llandeilo formation	1200 feet.
Caradoc formation	2500 ,,

Tertiary or Cainozoic.		Mineral accumulations of historic period, Pleistocene, Pleiocene, Miocene, Eocene.
Secondary or Mesozoic.	Cretaceous.	Chalk of Maestricht and Denmark, Ordinary chalk with and without flints, Upper green sand, Gault, Shanklin sands, Vecten Neocomian or lower green sand, Wealden clay, Hastings sands, Purbeck series.
	Jurassic or Oolitic.	Portland oolite or limestone, Portland sands, Kimmeridge clay, Coral rag with its grits, Oxford clay with Kelloway's rock, Cornbrash, Forest marble and Bath oolite, Fullers' earth, clay, and limestone, Inferior oolite and its sands, Lias upper and lower with its intermediate marlstone.
	Triassic.	Variegated marbles, Muschelkalk, Red sand stone, grès bigarré, bunter sandstein.
Primary or Palæozoic.	Permian.	Zechstein, dolomitic and magnesian limestone, Lower new red, conglomerate and sandstones, Coal measures.
	Carboniferous Limestone.	Carboniferous and mountain limestone with its coal, sandstone, and shale in some districts, Carboniferous slates and yellow sandstones.
	Devonian.	Modifications of old red sandstone.
	Silurian.	Upper Ludlow rocks, Wenlock shale and limestone, Woolhope limestone, Middle Caradoc sandstone and conglomerate, Lower Landeilo, Bala and Snowdon beds.
	Cambrian.	Barmouth sandstone, Penrhyn slates, Longmynd rocks, and various rocks below the Silurian.
Hypozoic.	Mica Schist.	Beds of mica schist consisting of quartz and mica with or without feldspar or garnets, chloritic schist, talc schist, quartz rock, clay slate, limited beds of iron ore.
	Gneiss.	Beds of gneiss consisting of laminæ of quartz, feldspar and mica; beds of mica schist, quartz rock, limestone, hornblende schist.
Primitive or Igneous.	Syenite, Porphyry, Basalt, Porphyritic granite.	The relative position and age of these rocks is more or less uncertain, though it seems probable that they may stand in the order here assigned to them.
	Granite.	This system of igneous rocks descends to an undefined depth, and is assumed to rest upon the internal liquid nucleus of the globe.

Wenlock formation	1800	feet
Ludlow formation	2000	,,
Old red sandstone	1000	,,
Carboniferous or mountain limestone	1500 to 2500	,,
Millstone grit	500 to 700	,,
Coal formation	3000	,,
Lower new red Pontefract rock	100	,,
Magnesian limestone	300	,,
New red sandstone	1000	,,
Lias	1000	,,
Lower or Bath oolite	400 to 900	,,
Middle or coralline oolite	300 to 800	,,
Upper or Portland oolite	200 to 800	,,
Greensand formation	——	
Chalk formation	——	
Lower tertiary or eocene, about	1200	,,
Miocene formation.		
Pleiocene.		
Pleistocene.		

Rough as this approximation is, it may give some idea of the general thickness, at least, of the stratified part of the crust of the earth. It would appear from combining these results, that the total thickness of the stratified crust, as far as these observations go, varies from 10 to 20 miles. Of this thickness the lower, or palæozoic strata, constitute the principal part, as will be seen by the annexed diagram given by Professor Phillips.



48. To the question as to the lapse of time during which these successive sedimentary strata have been formed, it is impossible to give any answer even as definite as the estimates of their thickness. All that can be said is, that the deposition from turbid waters being generally a slow process, it may be imagined that intervals of time of vast duration must have been required for the formation of strata which measure many miles in thickness.

But besides the mechanical deposition of matters suspended in water, we find numerous traces of chemical decomposition, which could only have been effected in long intervals of time. Thus deposits of limestone lie in frequent alternation with sandstones and clays. These indicate a series of changes in the mode of action, by which the total stratified mass was produced, consisting of successive cessations and renewals in chemical and mechanical action.

In short all these effects combined with others, presently to be mentioned, lead to the conclusion that the period during which the human race and its contemporary tribes have existed upon the earth, is but a brief interval compared with the immense lapse of time occupied by the formation of the igneous rocks, by the cooling down of the superficial part of the fused matter, and the subsequent deposition of the stratified crust.

49. It may be useful here briefly to recapitulate the history of the globe, as we find it inscribed upon its crust.

Originally a mass of fluid matter, in a state of igneous fusion, it assumed the globular form in virtue of the mutual gravitation of its parts. Launched by the Creator into space with a motion of rotation round a certain diameter as an axis, it took the form of an oblate-elliptical spheroid, flattened at the poles, in virtue of the centrifugal force attending its rotation. The degree of spheroidal ellipticity being of course precisely that which corresponded to its velocity of rotation.

In this state its extremely exalted temperature would not only maintain the matter at its surface in a state of fusion, but would also keep a certain portion of the solid matter in a state of sublimation, and all the liquid matter in a state of vapour suspended in and mixed with the surrounding atmosphere.

After a continuance of greater or less duration in this state, the heat of the globe being continually radiated into the surrounding space, the temperature of its surface would be gradually diminished, and would, at length, fall below the point of fusion of the matter composing its surface, and consequently the superficial part would be solidified, and the globe would be coated, as it were, by a thin skin or shell of solid matter, enclosing within

it the matter still remaining in fusion. By the continued effect of radiation the temperature of the surface would continually decrease, and consequently the thickness of the solidified shell would be continually augmented. At length the superficial temperature would fall to such a point that the sublimated matter would be precipitated on the surface, and when the superficial temperature, falling still lower, would descend below the boiling point of water, a general condensation of the vapour sustained in the atmosphere would ensue, and the entire surface of the globe would be covered with an ocean of uniform depth.

If no disturbing force acted, this would have continued to be the condition of the globe; but the fused matter enclosed by the solid crust being subject to effects more or less irregular, and exercising unequal pressures, it was in some places protruded upwards, and in others depressed. In this manner certain parts of the solid crust were pushed above the level of the water, while others may have suffered corresponding depressions. Instead, therefore, of a universal ocean, the surface became diversified by land and water.

The action of the water upon the subjacent solid crust of the earth by erosion and disintegration and exposure to atmospheric action, produced various changes in its condition; and the parts thus washed off being subsequently deposited at the bottom of the waters, produced the incipient stratification which has been above described.

When the temperature of the globe was reduced to such a point as to be compatible with the existence of organised bodies, the first forms of life were called by the Creator into existence, and were such as were adapted to the then physical condition of the globe, being, as might be expected, exclusively marine tribes. When subsequently land emerged from the ocean, and by the condensation and precipitation of vapour rivers and lakes were formed, terrestrial, fluviatile, and lacustrine tribes were called into existence.

50. As each successive stratum was thus formed, the remains of the animals and vegetables of the epoch were deposited in them, and have accordingly been preserved to our times. Fluviatile and land animals, in greater or less numbers, were swept into the embouchures of rivers, and there deposited like the others. Lacustrine tribes were, in like manner, deposited in the bottoms of vast lakes or inland seas.

51. But, besides these, there are indications of other changes either gradual or sudden, which would explain the deposition of terrestrial organic remains in the strata. There are evidences that the swellings upwards and subsidence downwards of the

crust, by the internal movements of the fluid nucleus of the globe, caused various changes in the distribution of land and water, so that parts of the globe which at one time were raised above the waters, and inhabited by terrestrial tribes, were subsequently submerged; while other parts, being elevated, emerged from the waters and formed new continents or islands. Indeed, changes which are in actual progress, and which will be presently noticed more fully, show that such phenomena are still produced, though probably on a much smaller scale, than at the earlier stages of the growth of the earth when its crust, having less thickness and strength, offered less resistance to the internal movements of its fluid nucleus.

52. Since the strata were deposited during a succession of periods of long duration, each receiving the remains of the organised tribes which inhabited the earth at the period of its deposition, it follows that the organic contents of these successive strata may be regarded as so many museums presenting to us specimens of the zoology and botany of the globe at the successive periods of their deposition. By examining, therefore, these remains, we shall be able to compare with each other, and with the existing tribes, the living inhabitants of the globe at the several periods of the formation of these strata.

53. The first and most obvious inference suggested by such an analysis is, that the number and variety of organised beings has rapidly increased, from the period at which the earth became habitable to the present epoch. This is rendered evident by a comparison of the number of species found in a given thickness of strata, proceeding downwards from the surface, which has been estimated by Professor Phillips as follows:—

	Number of Species in 1000 feet thickness.
Tertiary	1410
Cretaceous	707
Oolitic	456
Triassic, Permian	82
Carboniferous	47
Silurian	27

These numbers represent the relative proportion of marine species, by far the most numerous of the organic remains, more especially in the lower strata. This calculation was based upon the results of observations made about 1834, and consequently the numbers given are considerably below what would be obtained from more recent observation; but their proportion, which is all that concerns us here, would probably not be altered by subsequent results.

54. Since, therefore, it appears that the globe, through a long series of periods, has been tenanted successively by various races and tribes, both animal and vegetable, it is a question of profound interest to determine whether creative power, in the production of these organic beings, has operated upon the same principles which are manifested in the structure of its actual inhabitants. It might, for example, be imagined that the forms of life at those distant epochs, existing probably under extremely different physical conditions, might be totally different from, and utterly incomparable with, those which now prevail. Or though they might agree in certain general principles and conditions, they might be expected to exhibit extreme differences in many important details. A survey, nevertheless, of the existing tribes, and a comparison of them with the remains found in the terrestrial strata, lead to the conclusion, that though the former inhabitants of the globe differed from the present in many minute details of their structure, yet they agreed in all the more essential principles.

Naturalists have resolved the existing animal kingdom into four primary divisions: the *Vertebrates*, the *Articulated* or *Annulated*, the *Mollusca*, and the *Zoophytes*.

Quadrupeds, birds, and fishes, for example, are Vertebrated animals; insects, spiders, and certain shell-fish, such as crabs and lobsters, present examples of Articulated animals; snails and oysters are examples of Mollusca; and star-fish, sea-blubber, and corals, of the class of Zoophytes.

Now a due examination of the organic remains deposited in the terrestrial strata leads to the conclusion, that they admit of precisely the same general zoological division.

But the analogy between present and past creations is still closer when those primary divisions are resolved into several classes. Thus the living vertebrates are divided into mammifers, birds, reptiles, amphibia, and fishes. In like manner the fossil vertebrates admit of precisely the same classification. We find among them all these classes and no others.

Again, the living articulated animals are resolved into the subordinate divisions of insects, myriapodes, arachnida, crustacea, and worms of various forms. A like subdivision is applicable to fossil Articulata.

Fossil, like living, Mollusca are resolved into Cephalopodes, Gasteropodes (snails), Acephala (oysters and mussels), Bryozoaria (plumatella), and others. In fine, the Zoophytes, fossil as well as living, are resolved into Echinodermata (sea-urchin, star-fish), Polyparia (coral), Infusoria (monads), and Spongyaria (sponges), all of which are found reproduced in the fossil state.

55. But when we descend to more minute distinctions we cease

to find the same close correspondence. Genera or families of the above-mentioned classes are found among existing species which are altogether absent from the fossils; and, on the other hand, numerous genera of fossil animals have no place in the existing animal kingdom. Of about 1000 fossil genera, somewhere about 500 are identical with those of existing animals, the other 500 being extinct.

The difference between the present and past creations is, as may be expected, still more remarkable when we come to compare species with species. Thus of 10000 well-ascertained fossil species there are not more than 200 or 300 which still survive.

56. Though the counterparts of all the principal divisions of the animal kingdom are thus found in the fossil state, they are by no means equally distributed through the strata. Nature, on the contrary, seems to have called them successively into existence, according to their increasing perfection of organisation,—the Mammalia, the most perfect of all, being the most recent in date; and the Zoophytes and Mollusca, the lowest in their organisation, the earliest.

Thus the first forms of life which appeared during the Silurian period were chiefly confined to the Zoophytes and other classes of the lowest organisation, the only Vertebrates then existing being fishes, and those in very limited numbers. The same forms, for the most part, prevailed upon the globe during the Devonian and Carboniferous periods. During the Permian and Triassic periods animated nature received no other increase than that of a few reptiles. No other classes were added to the creation during the long interval of the Oolitic period; but the number of species of reptiles, as of all the other classes just mentioned, were considerably increased.

The first appearance of birds was manifested during the Cretaceous period, but they were very limited in number until the Tertiary period.

It was not till the Tertiary period which immediately preceded the present epoch that Mammalia were created. Birds, reptiles, and fishes augmented in number and variety also during this period, as did various others of the inferior classes, such as Gasteropodes and Acephala.

It must be observed, however, that foot-prints of some Mammalia have been discovered in the Oolitic strata, and marks, supposed to be those of birds, in the Triassic.

57. In the following table, compiled from the very extensive tables of Paleontology, which accompany the work of Professor d'Orbigny, we have exhibited the commencement, continuation, and prevalence of the different classes of animals which inhabited

the earth during the successive periods from the Silurian to the Human. The relative numbers of each class prevailing at the different periods are indicated by the four following signs:

∵ least.
× more numerous.
△ still more numerous.
⊙ most numerous.

Classes.	Silurian.	Devonian.	Carboniferous.	Permian.	Triassic.	Oolitic. Early.	Oolitic. Middle.	Oolitic. Late.	Cretaceous. Early.	Cretaceous. Middle.	Cretaceous. Late.	Tertiary. Early.	Tertiary. Middle.	Tertiary. Late.	Human Period.
Polyparia	∵	∵	∵	∵	∵	∵	×	×	∵	×	∵	∵	×	∵	⊙
Crinoidea	△	△	⊙		∵	∵	×	∵	∵	∵	∵	∵	∵	∵	∵
Ophiuroidea, Asteroidea, Echinoidea, Echinodermata	∵	∵	∵	∵	∵	∵	×	∵	∵	×	△	×	×	×	⊙
Bryozoaria	∵	×	×	∵	∵	∵	△	∵	×	△	⊙	×	△	×	△
Brachiopoda	△	⊙	△	×	×	∵	×	∵	△	△	△	∵	∵	×	∵
Acephala	∵	∵	∵	∵	∵	×	×	×	×	△	△	△	△	△	⊙
Marine Gasteropodes	∵	∵	×	∵	∵	∵	×	∵	×	×	×	△	△	△	⊙
Fluviatile Acephala								∵	∵			×	×	×	⊙
Terrestrial and Fluviatile Gasteropodes									∵	∵	∵	△	△	△	⊙
Acetabuliferous Cephalopodes					∵	∵	×	∵	∵	∵	∵	∵	∵	∵	⊙
Tentaculiferous Cephalopodes	⊙	△	△	∵	∵	∵	∵	∵	△	×	△	∵	∵	∵	∵
Fishes	∵	∵	×	∵	∵	∵	×	∵	∵	∵	×	△	×	∵	⊙
Reptiles				∵	×	∵	△	∵	×	∵	∵	∵	×	×	⊙
Birds					?				∵		∵		∵	×	⊙
Mammalia							?					∵	∵	×	⊙

58. It appears that the creation of fishes, reptiles, birds, and mammalia, the four vertebrated classes, underwent a sudden and large augmentation at the epoch of transition from the tertiary to the human period, and that, to crown all, man appeared for the first time in the period to which he has given his name. Among the infinite variety of fossils discovered in the strata of the earth, there is no instance of human remains.

59. Although the various classes of animals and vegetables, when once called into existence, have continued to prevail upon the earth till the present time, the same is not true of the genera constituting these classes, and still less of the species of these genera, as already mentioned. Species appear in particular strata, no trace of which is found in any other, superior or inferior. The inference is, that such animals existed only during the period corresponding to the deposition of these particular strata.

It happens sometimes that particular species prevail through certain groups of strata, superposed in regular order, but totally disappear from all subsequent and antecedent. Such species are accordingly characteristic, not indeed of particular strata, but of those limited groups of strata in which they prevail, and the inference is, that they had continued to exist upon the earth during the period corresponding with the deposition of the groups, but did not exist there before or after.

60. The species which thus prevailed upon the earth during geological periods more or less limited, and which ceased to exist before the period marked by the presence of the human race, have accordingly supplied to the geologist tests for the identification of strata much more determinate than any which depend on their mineral constituents. When the presence of a particular species is strictly limited to particular strata, it becomes an unerring test of the presence of that stratum wherever this species is found. If it has prevailed through groups of strata, it is a test, though not of particular strata, still of the group to which its presence is limited.

61. Numerous examples of these characteristic species may be mentioned. A certain family of Crustacea, called TRILOBITES, are almost exclusively limited to the Silurian period, appearing rarely in the lower bed of the carboniferous limestone, and never above them.

62. The Trilobites consisted of an oblong body, divided transversely into three parts, and also longitudinally into the same

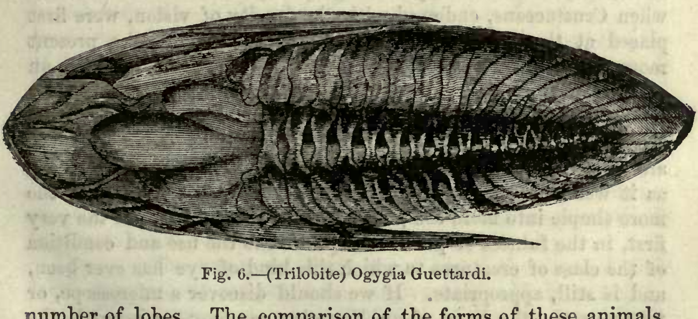


Fig. 6.—(Trilobite) Ogygia Guettardi.

number of lobes. The comparison of the forms of these animals with those of existing Crustacea, renders it probable that they dwelt in the depths of the sea, far from coasts, floating on their back, and never resting, inasmuch as their feet could not retain them stationary, and movement was necessary for their respiration. From a peculiarity of the mouth, it is inferred that they were carnivorous, preying probably on naked Mollusca or

Annelida, with which their remains are found associated. But one of the most interesting facts connected with them is the structure of their eyes, which resemble those of insects described in our Tract on "Microscopic Drawing." They consist of a vast number of minute lenses of octagonal form, set in the ends of tubes arranged side by side, so as to produce a radiating mass of eyes, enabling the animal to look at the same time in every direction. As many as four hundred of these lenses have been found set in a single cornea.

63. Such a structure proves, if proof were wanted, that the properties of light, and of the transparent media constituting the atmosphere and water, were, at the remote epochs when the earth was tenanted by those creatures, what they now are. "With respect to the waters," says Dr. Buckland, in reference to these creatures, "we conclude that they must have been pure and transparent enough to allow the passage of light to organs of vision, the nature of which is so fully disclosed by the state of perfection in which they are preserved. With regard to the atmosphere, also, we infer, that had it differed materially from its actual condition, it might have so far affected the rays of light that a corresponding difference from the eyes of existing Crustaceans would have been found in the organs on which the impressions of such rays were then received. Regarding light itself, also, we learn, from the resemblance of these most ancient organisations to existing eyes, that the mutual relations of light to the eye, and of the eye to light, were the same at the time when Crustaceans, endowed with the faculty of vision, were first placed at the bottom of the primeval seas, as at the present moment. Thus we find among the earliest organic remains, an optical instrument of most curious construction, adapted to produce vision of a peculiar kind, in the then existing representatives of one great class in the articulated division of the animal kingdom. We do not find this instrument passing onwards, as it were, through a series of experimental changes, from the more simple into more complex forms: it was created, at the very first, in the fulness of perfect adaptation to the use and condition of the class of creatures to which this kind of eye has ever been, and is still, appropriate. If we should discover a microscope, or telescope, in the hand of an Egyptian mummy, or beneath the ruins of Herculaneum, it would be impossible to deny that a knowledge of the principle of optics existed in the mind by which such an instrument had been contrived. The same inference follows, but with cumulative force, when we see nearly four hundred microscopic lenses set side by side in the compound eye of a fossil trilobite; and the weight of the argument is multiplied

a thousand-fold, when we look to the infinite variety of adaptations by which similar instruments have been modified, through endless genera and species, from the long-lost Trilobites of the transition strata, through the extinct Crustaceans, and the countless hosts of living insects. It appears impossible to resist the conclusions as to unity of design in a common Author, which are thus attested by such cumulative evidences of Creative Intelligence and Power; both as infinitely surpassing the most exalted faculties of the human mind, as the mechanisms of the natural world, when magnified by the highest microscopes, are found to transcend the most perfect productions of human art."

64. In like manner the lias, which is the earliest deposit of the Oolitic period, is characterised by various organic remains, as well of reptiles as of mollusca and the lower divisions. Among the latter may be mentioned a particular species of Ammonites, called the Ammonites Bucklandi, and among the former the ichthyosaurus,

Fig. 7.—The Ichthyosaurus.

or fish-lizard, is an example of an extinct animal of this tribe, which has the muzzle and general aspect of a porpoise, the head of a lizard, the teeth of a crocodile, the vertebræ of a fish, the sternum or breast-bone of an ornithorhynchus, and the fins of a whale. The enormous magnitude of the eyeballs was one of the peculiarities of this genus. The cavities in which they were lodged, in one of the species, measured not less than fifteen inches in diameter. A ring of bony plates surrounded the socket, which apparently seemed to protrude more or less the globe of the eye, and vary the convexity of the cornea, so as to adapt the organ for near or distant vision. This, combined with the great power of the fins or propellers, must have conferred upon the reptile great promptitude in perceiving and seizing its prey.

These reptiles were essentially aquatic, and the form of their teeth proves them to have been carnivorous. Their coprolites, or fossilised excrements, show that their intestine was spirally arranged, like that of certain fishes.

65. The Wealden strata, lying near the upper part of the oolitic and the lower part of the cretaceous, is characterised by remains of the Monocotyledonous * division of plants, by ferns, by various

* Having only one seed-lobe.

tribes of the lower animals, by insects, fishes of the genus Lapidotus, and, among the colossal class of reptiles, by the Hylæosaurus, and among terrestrial quadrupeds, by the Iguanodon.

66. Among the numerous animals characteristic of the Cretaceous period may be mentioned the Mososaurus of Hoffman, the Belemnites mucronatus, the Terebratula plicatilis.

67. In cases where a group of strata is characterised by the prevalence of a particular family of fossils, which first appear at its

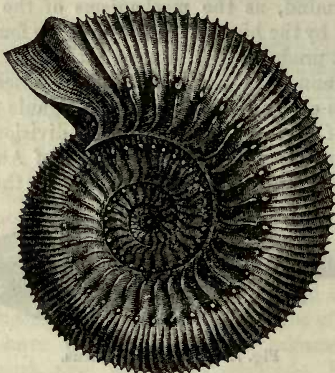
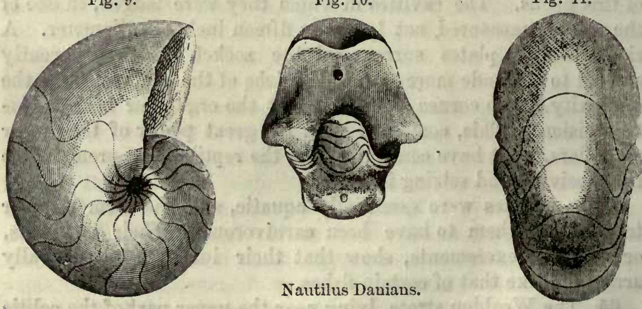


Fig. 8.—Ammonites Humpriasiamus.

lowest, and finally disappear at its uppermost layer, the succeeding strata are often distinguishable one from another, by the prevalence in them of a different species of this generic family. Thus

Fig. 9. Fig. 10. Fig. 11.



Nautilus Danians.

for example, the Ammonites, so called from their spiral form, resembling the horn sculptured on the head of Jupiter Ammon, commence in the Silurian and finally disappear after the chalk.

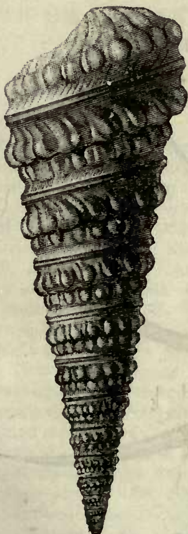
But each stratum, from that in which the family first appears

to that in which it disappears, is distinguished by the presence of a peculiar species. Of 222 species of Ammonites 17 belong to the oldest fossiliferous rocks, 7 to the carboniferous system, 15 to the new red sandstone, 137 to the oolite, and 47 to the chalk.

68. Among the organic remains characteristic of strata or groups of strata, the following examples may be mentioned: Fossil Cephalopodes are exceedingly numerous in the palæozoic group; but of all the genera hitherto discovered, one only, that of the nautilus, has come down to the present times.

These fossils appear in great numbers in the lower strata of the secondary rocks, are few in the lias and oolite groups, re-appear in great numbers again in the cretaceous, and nearly disappear from the tertiary rocks.

The examples are so numerous, and preserved in such perfection, that it is difficult to select any in preference to another, as illustrations of their forms. The nautilus, the only surviving genus of the Tentaculiferous Cephalopodes in the first periods of animal life, had nearly the form which it still retains.



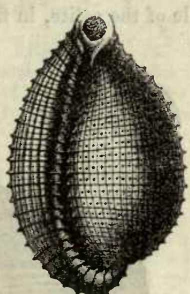


Fig. 13.—Cypræa Elegans.

Fig. 12.—Murchisonia Bigranulosa.

69. Fossil Gasteropodes are, like the Cephalopodes, extremely numerous. The terrestrial and fluvial genera have in general appeared for the first time in the Tertiary period; but marine

genera have been found in all the rocks from the Silurian upwards, and in gradually increasing numbers. They were, therefore, among the earliest manifestations of animal life on the globe; and what is remarkable is, that most of the genera, including even those of the Silurian period, still survive.

The close analogy of these ancient forms with the existing species will be manifest, by some examples taken from among the countless numbers of fossil shells collected by geologists.

A fossil shell from the Permian group is shown in fig. 12, and one found in all the tertiary beds, in fig. 13.

One of the genera which first appears in the middle strata of

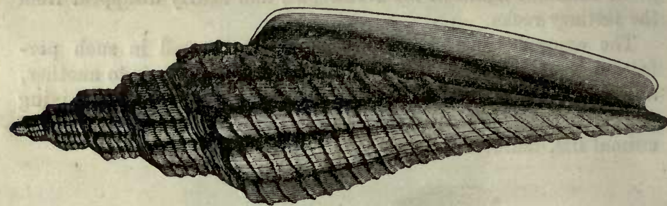


Fig. 14.—Voluta Egata.

the cretaceous group is shown in fig. 14, and one which begins in the middle of the oolite, in fig. 15.

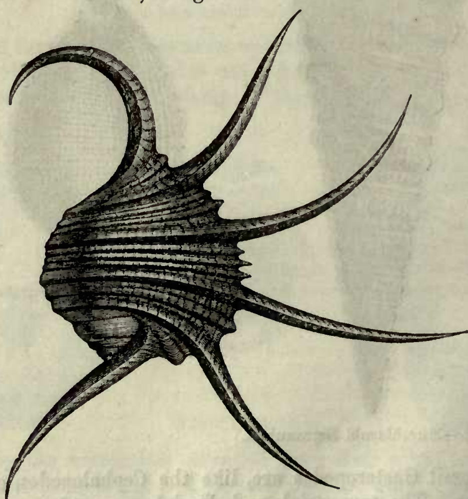


Fig. 15.—Pterocera Oceani.

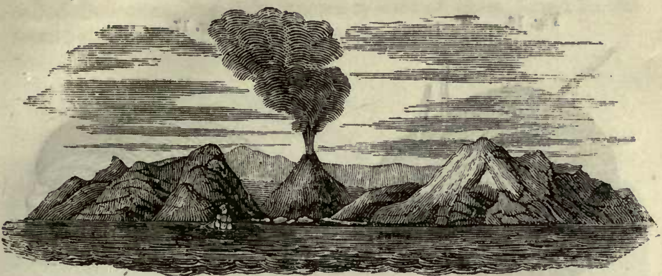


Fig. 66.—BARREN ISLAND IN THE BAY OF BENGAL.

THE CRUST OF THE EARTH;

OR, FIRST NOTIONS OF GEOLOGY.

CHAPTER III.

70. Spondylus.—71. Pentamerus.—72. Reticulipora.—73. Ceratites.—74. Enormous masses of animal remains forming entire islands and continents — Ehrenberg's discoveries.—75. Dr. Mantell's table of organic strata.—76. Forms of life in the Silurian period.—77. Sir R. Murchison's observations on the changes of the forms of life from period to period.—78. Stratification in undisturbed plains horizontal.—79. Strata thrown into oblique positions by disruption of igneous rocks.— 80. Formation of mountains. — 81. Arrangement of strata on their flanks. — 82. Strata sometimes upheaved without being disrupted.— 83. Sometimes disrupted. — 84. Sedimentary strata deposited subsequently to disruption — discordant stratification. — 85. How these supply data for determining the epoch of the disruption.—86. Determination of the relative ages of mountains—Cumbrians and Grampians much older than the Alps.—87. How inclined strata have enabled geologists to analyse the structure of the terrestrial crust to the level of the igneous rocks.—88. Erosion of stratification by the action of water, and the subsequent deposition of other strata.—89. Basalts—their character and composition.—90. Various forms of basaltic rocks.—91. Their extensive diffusion over all parts of the earth.—92. Their columnar structure—Giant's Causeway.—93. Basaltic causeway of the Volant—Dykes and colonnade of Chenavari.—94. Veins of basalt.—95. Basalts in mounds.—96. Basaltic grottoes—Kase grotto of Bertrich-Baden—Fingal's Cave.—97. Trachytic rocks.—98. Trachytic mountains.—99. Their origin igneous.

70. THE Spondylus, figs. 16, 17, of which there are forty-five

Fig. 16.

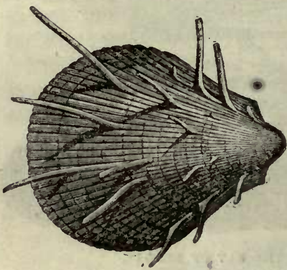
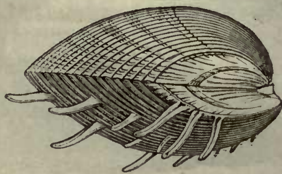


Fig. 17.



Spondylus Spinosus.

fossil species, first appears in the lowest stratum of the cretaceous group, and presents an example of the fossil Lamellibranchiæ.

71. The Pentamerus, figs. 18, 19, of which there are twenty-one fossil species, is an example of the Brachiopoda. This is

Fig. 18.

Fig. 19.

Pentamerus Knightii.

first seen in the lowest strata of the silurian group, and becomes extinct after the Devonian period, so that its existence was limited to the earliest epochs of animalisation.

72. The Reticulipora, figs. 20, 21, 22, 23, an example of the Bryozoares, is an extinct genus Retepora, of which there are five fossil species known; the first in the middle strata of the oolites, and the others in the upper strata of the cretaceous group. In this the meshes are formed of high vertical laminæ, supplied with cells by transverse lines on each side; fig. 20 shows the whole in its natural size; fig. 21, the external part magnified; fig. 22, the internal part magnified; fig. 23, the laminæ as shown with a still higher magnifying power.

73. The Ceratites belong to the family of the mollusca called Bacculine, the only known species of them found in the lowest strata of the cretaceous system.

Fig 20.

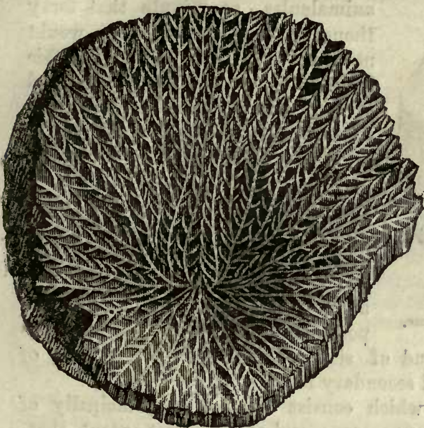


Fig. 22.

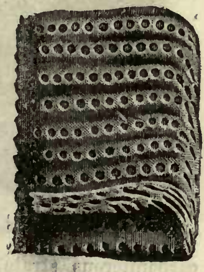


Fig. 21.

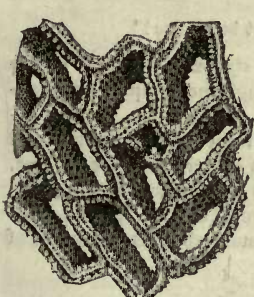


Fig. 23.

Reticulipora obliqua.

74. Among the most wonderful results of the animalisation of the earth, in the remote geological periods, is the enormous extent of matter which various species of animals elaborated from the gaseous or liquid element around them, by vital action, and which have remained as a perpetual record of their presence. Whole islands, and even continents, have been produced by the secretive functions and other vital agencies of countless myriads

of these living instruments. Ehrenberg, the celebrated Prussian microscopist and naturalist, mentions a stratum in Germany, not less than 14 feet in thickness, composed exclusively of the shells of animalcules, so minute that forty thousand millions of them would not fill a space greater than a cubic inch. Mountains, hundreds and even thousands of feet in height, are found to be composed exclusively of organic matter. The strata of vegetable origin are not less extensive, consisting of forests engulfed by the subsidence of vast tracts of land, or embedded in the mud of rivers and estuaries, of lignite and brown coal in the tertiary deposits, of coals and shales in the carboniferous strata, and of silicified and calcified trunks of trees in the tertiary and secondary formations.

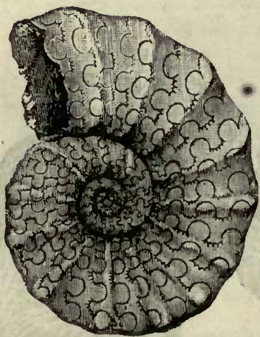


Fig. 24.—Ceratites Nodosus.

75. But the strata which consist wholly or principally of animal remains are so numerous, and of such vast extent, that, as Dr. Mantell observed, the exclamation of the poet may be reiterated by the philosopher,

"Where is the dust that has not been alive?"

for there is not an atom in the superior strata of the crust of the globe that has not probably passed through the complex and marvellous laboratory of vitality.

The various families of animals from the infusoria and zoophytes, up to man himself, have then contributed more or less, by their organic remains, to form the solid crust of the globe. The following table, taken from the work of Dr. Mantell, presents a concise view of some of the most obvious examples of these remarkable deposits.

Rocks Composed wholly or partly of Animal Remains.

Strata.	Prevailing Organic Remains.	Formations.
Trilobite schist . .	Trilobites	Silurian system.
Dudley limestone . .	Corals, crinoidea, crustaceans, shells, &c.	,,
Shelley limestone .	Brachiopodous shells . . .	,,

Rocks Composed wholly or partly of Animal Remains.		
Strata.	**Prevailing Organic Remains.**	**Formations.**
Mountain limestone	Corals and shells	Carboniferous system.
Encrinital marble	Crinoidea and shells	,,
Mussel-band	Fresh water mussels	,,
Ironstone nodules	Trilobites, insects, and shells	,,
Lias-shales and clays	Pentacrinites, reptiles, fishes	Lias.
Limestone	Terebratulæ, and other shells	,,
Lias conglomerates	Fishes, shells, corals	,,
Gryphite limestone	Shells, principally gryphites	,,
Shelley limestone	Terebratulæ, and other shells	Inferior oolite.
Stonesfield slate	Shells, reptiles, fishes, insects	Oolite.
Pappenheim schist	Crustacea, reptiles, fishes, insects	,,
Bath stone	Shells, corals, crinoidea, reptiles, fishes	,,
Ammonite limestone	Shells of cephalopoda, principally ammonites	,,
Coral rag	Corals, shells, echini, ammonites	,,
Bradford limestone	Crinoidea, shells, corals, cephalopoda	,,
Portland oolite	Ammonites, trigoniæ, and other shells	,,
Purbeck and Sussex marble	Fresh water-shells and crustacea	Wealden.
Wealden limestone	Cyclades and other fresh-water shells, crustacea, reptiles, fishes	,,
Tilgate grit (some beds)	Bones of reptiles, fishes, fresh-water shells	,,
Farringdon gravel	Sponges, corals, echini, and shells	Green sand.
Jasper and chert	Shells	,,
Green sand	Fibrous zoophytes	,,
Chalk	Polythalamia and other animalcules	Cretaceous.
Maestricht limestone	Corals, shells, ammonites, belemnites, and other cephalopoda, reptiles	,,
Hippurite limestone	Shells, principally hippurites	,,
Hard chalk (some beds)	Echini and belemnites	,,
Flints	Sponges and other fibrous zoophytes; infusoria, &c., echini, shells, corals, crinoidea	,,
Limestone	Fresh-water shells	Tertiary.
Nummulite rock	Nummulites	,,
Septaria	Nautili, turritellæ, and other shells	,,
Calcaire grossier	Shells and corals	,,
Gypseous limestone	Bones of mammalia (Palæotheria, &c.), birds, reptiles, fishes	,,

Rocks Composed wholly or partly of Animal Remains.		
Strata.	Prevailing Organic Remains.	Formations.
Lacustrine marl . .	Cyprides, phryganea, fresh-water shells	Tertiary.
Monte Bolca limestone	Fishes	,,
Bone-breccia . . .	Mammalia, and land shells . .	,,
Sub-Himalaya sand-stone	Bones of elephants, mastodons, reptiles, &c.	,,
Tripoli	Infusoria	,,
Semiopal . . .	Infusoria	,,
Richmond earth . .	Infusoria	,,
Guadaloupe limestone	Human bones, land shells, and corals	Human epoch.
Bermuda limestone .	Corals, shells, serpulæ, infusoria	,,
Bermuda chalk . .	Comminuted corals, shells, &c. .	,,
Bog iron ochre . .	Infusoria	,,
Siliceous limestone . .	. . . .	Tertiary.

Even in this list, extensive as it is, numerous strata in which animal remains largely predominate, have been omitted. In the tertiary and more recent deposits, every order of existing animated nature is found. The bones of man, however, are confined to the superficial part, which has been formed since the globe was peopled by the races which now inhabit it.

76. How completely changed the inhabitants of the earth have been from one geological period to another, may be inferred from the following observations of Sir R. Murchison. "Beginning," says he, "with the *vertebrata*, are not the fishes of the old red sandstone as distinct from those of the carboniferous system, on the one hand, as from those of the Silurian on the other? M. Agassiz has pronounced that they are so. Are any of the *crustaceans*, so numerous and well defined throughout the Silurian rocks, found also in the carboniferous strata? I venture to reply, not one. Are not the remarkable *Cephalopodus mollusca*, the *Phragmoceras*, and certain forms of *Lituites*, peculiar to the older Silurian system? Is there one species of the *Crinoidea* figured, known in the carboniferous strata? Has the *Serpuloides longissimus*, or have those singular bodies the *Graptolites*, or, in short, any zoophytes of the Silurian system been detected in the well-examined carboniferous rocks? And in regard to the corals, which are so abundant, that they absolutely form large reefs, is not Mr. Lonsdale, who has assiduously compared multitudes of specimens from both systems, of opinion, that there is not more than one species common to the two epochs?"

77. These anticipations of Sir R. Murchison have been more than realised by the subsequent researches of M. D'Orbigny, founded upon his own observations, which extended over a large portion of the New as well as of the Old world, and upon the entire mass of facts connected with the analysis of the crust of the earth collected by the observations of the most eminent geologists in all parts of the world. It appears from these researches, that during the long series of periods of geological time from the first appearance of organised life upon the globe, to the period in which the human race and the contemporaneous tribes were called into existence, the world was peopled by a series of animal and vegetable kingdoms, which were successively destroyed by violent convulsions of the crust, which produced as many devastating deluges. The remains of each of these ancient creations are deposited in a series of layers or strata one over the other; and from an examination of them it has been found that each successive animal kingdom was composed of its own peculiar species which did not appear in any posterior or succeeding creation, but that genera once created were frequently revived in succeeding periods; that many of these genera, however, became extinct long before the arrival of the human period; that during the human period no new genus was called into existence, except that of the human race, which, however, according to the idea of the most eminent naturalists, ought to be regarded as an order rather than a genus.

Each of the succeeding animal kingdoms which thus temporarily inhabited the earth consisted of many hundred species. Thus it has been ascertained by M. D'Orbigny, that there are deposited in the Cambrian or Lower Silurian strata not less than 418 species of the animals which inhabited the globe in the first period of its animalisation, and that these included specimens of all the principal divisions of animals from the Vertebrata downwards.

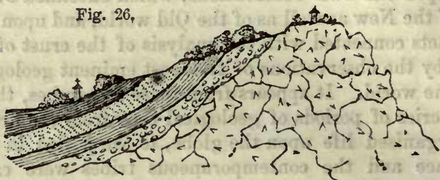
It will be sufficient, however, for the present, thus briefly to indicate these important discoveries, which we shall develop much more fully in the next volume of these series.

78. As already explained, the strata, when originally deposited, must in all cases have had a horizontal position, and they must succeed each other in their normal order, whenever the part of the earth at which they lie has undergone no disturbance subsequently to the date of their deposition, which has sometimes been the case with extensive plain countries. In such cases, therefore, a section of the crust would exhibit them in parallel and horizontal layers, as in fig. 25.

Fig. 25.

79. In undulating and mountainous countries it is found, however, that, instead of being horizontal, they are variously

Fig. 26.



inclined (fig. 26), and sometimes bent into, or even beyond, the vertical direction (fig. 27).

When it is considered that at the time of their deposition the strata must have been horizontal, it will be evident that the position shown in these figures could only have been given to them by a force acting from below, by which they were heaved upwards, and by which the crust was broken, the igneous rocks having forced themselves through it.

Fig. 27.

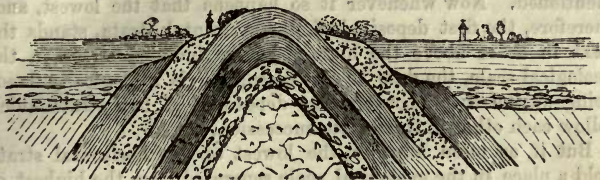
80. In such cases hills or mountains of greater or less elevation are formed, at the summits of which the igneous rocks which have been protruded through the stratified crust are at the surface, and the edges of the strata thus broken are ranged along the flanks, the lowest or most ancient being nearest the summit, and the others succeeding each other in their proper order in descending towards the adjacent valley or plain.

81. It will be evident that the stratum whose edge is highest on the mountain is that which lies the lowest on the plain, and that whose edge is lowest on the mountain is that which is highest or nearest the surface on the plain.

82. In the cases here exhibited the igneous rocks have split the stratified crust and broken quite through it. This, however, is not always the case. It often happens that the uplifting force loses its energy before the superincumbent strata are cracked, in which case they would cover the elevation preserving the order of their superposition, but would be, as before, inclined in accordance with the declivity of the hill produced by the uplifting force.

83. In other cases the superior strata, but not the inferior, are broken through, as shown in fig. 28. The edges of the disrupted

Fig. 28.



strata are then exposed upon the flanks of the elevation, and are ranged as above described; while the inferior strata, not disrupted retain their natural order upon the summit.

In other cases (fig. 29) the disruption is complete, and the

Fig. 29.

broken strata are ranged on each of the opposite declivities in the same order as already described.

84. It happens often that after the cessation of the disturbing force, by which the strata have been uplifted, the land having been again submerged, new depositions take place, the strata of which are of course horizontal and superposed upon those rendered oblique by the previous disturbance. This sort of superposition of strata is called by geologists discordant or unconformable stratification, and wherever it occurs it affords evidence of the action of a disturbing force from below, the geological date of which can be determined with more or less precision by a due examination and comparison of the superposed strata.

Cases of this kind of discordant stratification are shown in fig. 28 and fig. 29, in both of which horizontal strata deposited upon the oblique strata, are disposed along the slopes of the elevation.

85. It is evident that the epoch of the action of the disturbing force must, in all cases, have been posterior to that of the deposition of the inclined, that is, of the disturbed strata. It is equally apparent that the disturbing action must have ceased before the

deposition of the lowest of the superincumbent horizontal strata. The date of the disruption is therefore fixed geologically at some period between those of the deposition of the two strata just mentioned. Now whenever it so happens that the lowest, and, therefore, the first deposited of the horizontal strata, stands the next in order above the highest of the inclined strata in the geological scale, the date of the disruption is geologically fixed, being at the epoch between the deposition of two strata which follow each other in immediate succession.

But if, as often happens, the lowest of the horizontal strata hold a place in the geological scale separated from the highest of the inclined strata by several intermediate layers, which are locally absent, then the date of the catastrophe becomes more uncertain, inasmuch as it may have taken place at any epoch between those of the depositions of the highest of the inclined and the lowest of the horizontal strata.

86. Nothing is more beautiful or conclusive than the reasoning by which the geological dates of mountain-ranges have been determined by these means. One of the most interesting consequences resulting from the observation of such discordant stratifications as are here described, is the means they afford geologists of determining the relative ages of different ranges of mountains. Thus, for example, it is easily demonstrated that the mountains of Cumberland, Lammermuir, and the Grampians were raised above the surface of the ocean long before the Alps had burst the crust of the earth, and before even the continent of Europe was dry land. An examination of the slopes of these British ranges shows that the strata dislocated and inclined are those of the old slate and limestone, while the level strata superposed upon them in the adjacent plain are the more recent ones of the red sandstone. It follows that these ranges were raised above the waters posterior to the epoch of the deposition of the old slate and limestone, but antecedently to that of the red sandstone; and since the red sandstone has been deposited horizontally along their base, it follows that the land surrounding them was covered with water subsequently to their elevation.

An examination of the Alps gives a very different result. On the flanks of these mountains the tertiary strata are found inclined, sloping downwards, until they become level upon the general surface of Europe. It follows, therefore, that the date of the disruption to which the Alps owe their elevation was posterior to the deposition of the tertiary strata upon the European continent, while the elevation of the British ranges above mentioned was anterior to the deposition of the red sandstone; from which it follows that the Grampian, Lammermuir, and Cumbrian

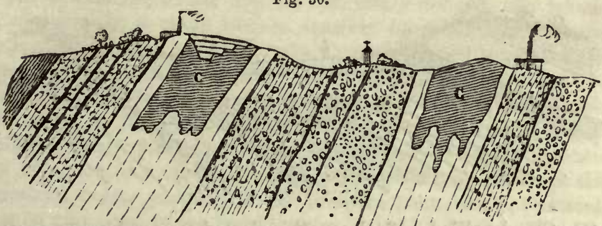
mountains were dry land, while the greater part of the continent of Europe was covered by the ancient ocean, and long before the Alps were reared above its surface.

In a subsequent tract this subject of the relative ages of the mountain system will be more fully developed.

87. From what has been here explained, and from inspection of figs. 26 to 29, the manner in which geologists have been enabled to analyse the crust of the earth to depths far exceeding any which could be reached by direct excavation, mining, or boring, will be easily understood. Nature herself, by these prodigious disruptions, has exposed to view the structure of the sedimentary strata in all cases where no subsequent deposition has taken place over them. By such disruptions it often happens that the strata are inclined over a large extent of country, the surface of which, intersecting their planes at a very oblique angle, is necessarily formed by the section of the strata in the order of their superposition, the breadth of the several sections being so much the greater, the more oblique the angle formed by the horizontal plane with the planes of the strata.

In fig. 30 the strata are represented inclined very slightly from

Fig. 30.



the perpendicular, and consequently the breadth of each stratum at the surface is very little greater than its actual thickness; but it will be easily understood that if the obliquity of the strata to a level plain were greater, a very thin stratum would present at the surface a considerable breadth. Supposing then the complete series of strata in any tract of country to be inclined at a very oblique angle to the level plain, it will be easily understood that in travelling in a direction at right angles to the lines of intersection of the strata with the surface, the succession of strata may be examined, and a much greater extent of their thickness submitted to observation, than could be accomplished by any artificial sections of horizontal strata.

88. Among the indications afforded by discordant stratifications of past convulsions to which the land has been subject, are some

which show that, by the violent agitation of the waters consequent on sudden changes of level of their bed, and of the parts of continents over which they have swept, strata already formed have been partially broken up and carried away by currents. Excavations, such as that represented in fig. 32, are explained in this manner.

Fig. 32.

In such cases it has often happened that the waters under which such broken strata were submerged, having again become tranquil, a new series of strata have been deposited horizontally, filling up the excavation thus formed, as shown in fig. 33.

Fig. 33.

89. Closely allied with the matter ejected from volcanoes are the Basaltic deposits, which form so grand a feature in the scenery of many countries with which travellers are familiar.

All the circumstances and characters which attend these rocks conspire to show that they have issued from openings in the crust of the earth in a state of fusion much more complete than that of volcanic lava, and in the process of cooling have, in many cases, been crystallised, so as to assume those remarkable varieties of the columnar form, so conspicuously developed in the north of Ireland, the Scottish Islands, and many other parts of the world.

The Basaltic rocks are characterised by a dark colour and a compact base of the mineral called *Labradorite*, including black pyroxene, generally the magnetic oxide of iron, frequently peridote, and sometimes crystallised feldspar, to which they owe their porphyritic structure.

90. The fluid basalt often assumes the form of prismatic columns in the process of crystallisation, consequent upon slow cooling. Mr. Gregory Watt imitated this artificially by reducing 7 cwt. of Dudley basalt to fusion and causing it to cool slowly, when globular masses were formed, which gradually enlarged and pressed one against the other, until they forced themselves into regular columns, resembling in all respects those of natural basalt.

In some places basalt forms vast plateaux of considerable thickness, in others it is found in detached sheets of less extent, at points of mountains, more or less distant one from the other, and at the same level, as if it had originally been a single sheet and had been disrupted, by the convulsions of which the mountains have been the result.

In some cases the basalts form isolated masses or mounds rising in the midst of plains, altogether removed from all similar formations. They are also often found in veins in the strata of the earth, like those of minerals. They sometimes also present themselves as extensive walls, or in a series of separate mounds having a common direction. When basaltic rocks are presented in the form of sheets or mounds, the upper part is generally composed of porous cellular scoriform matter, irregularly divided, and terminated below by a plane surface, sensibly horizontal. When the mass is composed of several layers, these layers are separated one from another generally by thin beds of rapilli.*

91. Basaltic deposits are much more extensively scattered over the surface of the globe than those of ordinary volcanic origin. Unlike volcanic products, they are not confined to particular centres of action, but appear to have been produced wherever the terrestrial crust, yielding to the pressure from below, was rent so as to give issue to the fused matter. In the British Isles basaltic products are found in various places, and more particularly in the north of Ireland and Scotland. In France they are found everywhere from the northern part of Auvergne to Montpellier, and even to Toulon. On the borders of the Rhine they extend from the Ardennes to Cassel, and are continued eastward into Saxony, Bohemia, and the surrounding countries. They prevail to a great extent in Iceland, are recognised in the West India Islands and St. Helena, in the island of Ascension, and in almost all the islands of the southern ocean.

92. The tendency of these rocks to form themselves into prismatic columns has more especially excited the attention of the curious. In some cases all the prisms converge to the summit of

* Volcanic dust.

a mound, which thus assumes a sheaf-like structure. In others they take the form of close columns with the most picturesque aspect. In others again, these columns, cut off at a certain level, form a sort of mosaic pavement, to which the name of causeway has been given. Of this one of the most magnificent examples is presented in the case of the Giant's Causeway, in the north of Ireland.

93. Examples of similar formations are presented in different parts of Europe, and especially in the Vivarais, in the department of Ardèche, in France. A remarkable series of basaltic causeways is there presented on the banks of the river Volant, between Vals and Entraignes, a view of which is given in fig. 31, p. 33. The colonnades of Chenavari, near Rochemaure, fig. 34, and the dykes which are near the same place, fig. 35, present examples of other varieties of basaltic forms.

94. Basaltic rocks, having all the prismatic characteristics above described, are frequently presented in the form of mineral veins. Examples of this are found in the central parts of France, and also on the borders of the Rhine. Most commonly the matter composing the vein is compact or divided by irregular cleavage, but it also sometimes exhibits the prismatic form, the axis of the prisms being horizontal, fig. 36.

95. When basalts take the form of a mound, the lower part of the mass often presents a multitude of appendages which

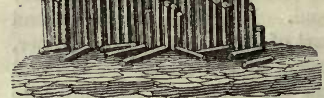


Fig. 34.—Colonnade of Chenavari, near Rochemaure.

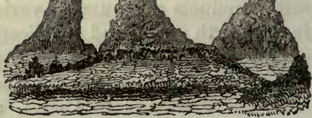


Fig. 35.—Dykes of Chenavari.

penetrate like roots into the subjacent earth; showing that the matter in a liquid state had flowed into the crevices, and moulded itself there. The earth thus in contact with the basaltic mass is often found calcined to a considerable depth, and the vegetable remains which it includes are carbonised. Examples of this are presented upon the cliffs of the plateau of

Mirrabel, in the Vivarais, descending towards St. Jean 'le Noir, fig. 38.

Fig. 36.

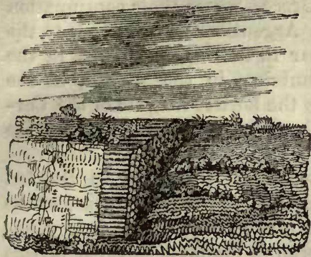
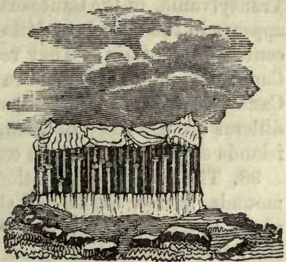


Fig. 38.



96. Grottoes, caves, and tunnels are often found in the midst of these basaltic masses, and in those of trap rocks, which have a close analogy to them. Examples of this may be seen in the Vivarais, on the borders of the Rhine, near Bertrich-Baden, between Trèves and Coblentz, where the columns forming the grotto consist of rounded blocks superposed, resembling a pile of cheeses, from whence the grotto has received the name of Kase Grotte, or Cheese Grotto, fig. 39. But by far the most magnificent of these basaltic grottoes is the celebrated Cave of Fingal, in the Island of Staffa, fig. 37, p. 49.

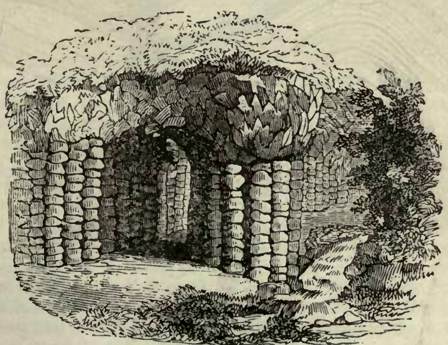


Fig. 39.—The Kase Grotto of Bertrich-Baden.

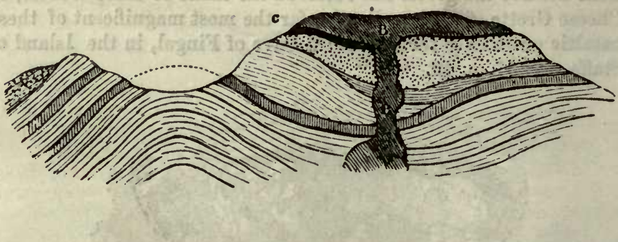
97. Another eruptive product of the terrestrial crust, still more extensive than the basalt, is the trachytic rocks, which form the celebrated Puy-de-dôme, in Auvergne, the Mont D'or, the Cantal,

the Mézenc, and the Mégal, upon the borders of the Velay and the Vivarais. They prevail also on the right bank of the Rhine, and the Siebengebirge. They form immense groups in Hungary and Transylvania, in the Caucasus, in Greece, where their continuation appears in the islands of Milo and Argentiera and extends to the centre of Santorin. They reappear in the Lipari Islands, in the Campania, in the Euganean mountains, in the Azores, in the Canaries, in South America, where the loftiest heights of the Cordilleras are composed of them, in Central Asia, and in many of the islands extending along its coast to Kamschatka.

98. The trachytic formation presents itself not only in isolated mounds, narrow bands, and sheets scattered over the surface of the globe like those of the basalt, but also in vast mountains, generally assembled in large groups, forming the most elevated masses and covered with terrific asperities. Their flanks are torn by precipitous valleys and deep gorges.

99. The matter composing these vast accumulations was evidently ejected from the bowels of the earth by the disruption of the crust, issuing in a state of pasty fusion through the opening thus made in the superjacent stratified rocks, fig. 40.

Fig. 40.



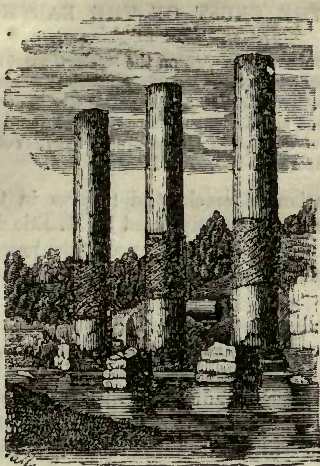


Fig. 52.

THE CRUST OF THE EARTH;

OR, FIRST NOTIONS OF GEOLOGY.

CHAPTER IV.

100. Elie De Beaumont's explanation of the formation of mountain chains —101. Effects of the earthquake of 1838 in South America.—102. Inference as to the probable effects of the vast earthquakes which produced the great mountain ranges.—103. Dislocations in parallel directions produced parallel chains.—104. Origin of mineral veins explained.—105. Veins are found in groups—generally parallel. —106. Deposition of rock-salt in cavities of Muschelkalk.—107. Natural agencies still manifested are sufficient to explain all geological phenomena.—108. Internal fluidity of the earth—109. Effects of internal heat on the surface.—Why the climates of the higher latitudes at former epochs were similar to those of the tropics at present—explanation of the presence of tropical fossils in polar latitudes.—110. The undulations and disruptions assumed by geologists as physical causes still proceed, though with less energy.—111. Effects of earthquakes—that of Calabria, 1783.—112. Effects in Sicily.—113. Earthquakes at Chili.—114. Earthquake of 1819 in India.—115. Like phenomena recorded in all ages and countries.—116. Similar phenomena traditional—island of Atlantis.—117. Permanency of the sea-level proves the undulations of the land.—118. Undulations of the Swedish peninsula.—119. Similar changes in Greenland, and in the Indian archipelago.—120. General sinking of South America.—121. Singular

example of a submerged forest on the western coast of America.—122. Temple of Jupiter Serapis.—123. Historical researches of Professor Forbes.—124. Tradition of a submerged city under Lough Neagh.—125. Why these undulations of the earth's crust might be expected.—126. Effects of disruption of the crust.—127. Volcanic eruptions of 1808 in the Azores.—128. The Monte Nuovo.

100. THE formation of cracks and fissures in the crust of the globe has been ingeniously explained by M. Elie de Beaumont, as the natural and necessary consequence of the process of superficial cooling taking place upon a globular mass of matter in a state of fusion.

To render intelligible the reasoning and theory of this eminent geologist and naturalist, let us suppose the globe, as we have formerly described it, to have been originally in a state of igneous fusion, and to undergo a gradual superficial cooling, by which a thin solid shell would be formed upon it. The contraction of this shell, taking place from its inner towards its outer surface, would leave a vacant space between the central mass in fusion and the concave interior surface of the solid shell. Supposing also, as we have formerly explained, that after the external surface had fallen below the temperature which maintains water in a state of vapour, the atmospheric vapours, being condensed, had fallen in rain; the external surface of the terrestrial spheroid would then have been covered with an ocean of uniform depth and would consequently have been totally destitute of land.

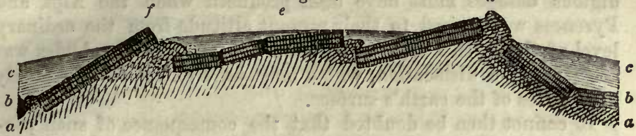
An imaginary section of a part of the terrestrial crust in this state is represented in fig. 41, where *b* is the solid crust, *a* the liquid central mass, *d* the intermediate vacant space, and *c* the ocean of uniform depth covering the entire surface.

Fig. 41.

But the state of equilibrium which would maintain this state of things could not continue. The internal fluid matter would press more or less upon the thin crust surrounding it, which being unequal in its structure, would offer proportionately unequal resistance, and consequently yielding at its weakest points would be dislocated as shown in fig. 42, the fragments being thrown into infinitely various positions. Thus the piece *f* being tilted obliquely, would be raised at one end above the surface of the ocean, depressed at the other. It would, therefore, form a chain of

mountains with a gentle declivity on one side, and abrupt precipices on the other, such as the Pyrenees and the Andes. In other places the two parts fractured would form gentle declivities on both sides,

Fig. 42.



as at *h*. The matter in fusion within the crust forcing its passage upwards in the opening between them would be solidified by the process of cooling on arriving above them. Thus chains of mountains would be formed of moderate declivities on both sides, having igneous rocks at their summits.

In fine, some fragments, such as *e*, would remain nearly level, and would be pushed above the surface, in which case they would form extensive plains of dry land, or might remain below it, in which case they would form the bottom of a shallow sea.

Thus we may understand in its most literal sense the brief description of the formation of the earth in the sacred records: "God divided the land from the water, and saw that it was good."

Such dislocations of the terrestrial crust would not be confined to a single catastrophe, but would from time to time be reproduced. According as, by the continued process of cooling, the solid crust of the earth became thicker and thicker, a vacant space would still be produced between its inner surface and the central fluid matter, and like consequences would from time to time ensue, so that the history of the earth would consist of a series of convulsions by which its crust would from age to age be disrupted, new chains of mountains being formed, and new continents being raised above the waters of the ocean and former ones submerged. Movements of the waters would necessarily attend each such convulsion, compared with which the most violent oceanic commotion with which we are familiar is tranquillity itself.

101. It is related that the earthquake of 1838, which took place at Chili, in South America, although it did not change the level of the continent by more than a few feet, produced effects at the enormous distance of 4000 miles, extending even to the islands of Oceania. The earthquake on the coast of Peru laid in ruins all the towns along the shore. At the moment of the shock, the waters of the ocean, raised with violence, were poured upon the coast, carrying with them an immense mass of sand and shingles,

and transporting vessels of the largest tonnage to a distance of four miles inland.

102. When such effects arise from a change of the surface not exceeding a few feet in elevation, it may be imagined what prodigious deluges must have been produced when the Alps and Pyrenees were raised to their present altitude from the ordinary level of the earth's surface, or when the chain of the Andes was elevated by a dislocation, which must have extended over nearly 3000 miles of the earth's surface.

It cannot then be doubted that the consequence of such convulsions would be universal; and some idea may be formed of the extraordinary ravages which the frightful deluges consequent upon them would occasion upon the surface of the earth, especially at the moment when all levels of land and sea were changed in consequence of the dislocation which caused them, and when a considerable mass of sediment still in a movable state was transported by the torrents of the ocean. It will not be considered extraordinary, that all the terrestrial animals should be at once destroyed by the immediate action of the waters, while the marine animals would suffer equal destruction by the violent transport of the terrestrial matter swept among them.

103. M. Elie de Beaumont has shown that these movements of terrestrial dislocation have never been partial, but that each of them has been produced along lines, having one uniform direction, as may be seen in the case of the Pyrenees, of certain ranges of the Alps, and upon a still greater scale in the case of the Andes and the Himalayas. We shall show more fully hereafter that the parallel lines of mountains have been raised at the same epoch, and that the succession of convulsions by which the ranges of mountains having different directions were produced, can be determined, and their geological dates assigned with more or less precision.

104. The circumstances which have been explained, attending the past history of the earth, have also produced cracks and fissures in its crust, through which the central liquid matter has been forced, and in which it has been solidified, forming veins of mineral matter different altogether from the strata which they intersect. These veins often contain earthy matter, such as carbonate of lime, sulphate of baryta, and quartz, in which case they offer but little interest. They are, however, more frequently filled, either wholly or partially, with metalliferous substances, in which case they acquire great importance. These metalliferous veins are generally found either in the igneous or in the most ancient of the stratified rocks.

105. It is rare that a single vein is met with. Most commonly

great numbers prevail in the same system of strata, and generally take a direction nearly parallel. Fig. 43 shows a transverse section of such a system. The similarity of the mineral matter which fills them demonstrates their common origin. It often happens that one system of such veins is intersected by another, presenting mineral contents totally different from the former. These are called *cross veins*. It is rare that a vein is completely filled with metalliferous matter. Most commonly, these substances form threads, *a*, *b*, *c*, *d*, *e*, *f*, *g*, fig. 44, more or less irregular, included in the middle of the stony crystalline matter which fills the vein. The thickness of the metalliferous thread varies at different parts of the vein; at some points it is considerable, and at others becomes very small, often vanishing altogether.

Fig. 43.

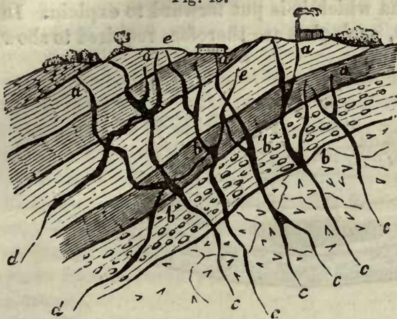
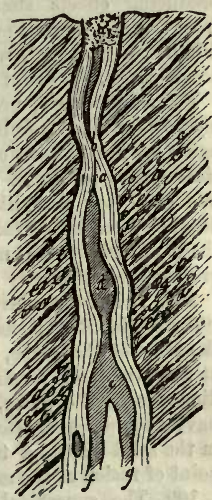


Fig. 44.



106. Numerous cavities are often formed in the midst of stratified rocks, probably by the dissolving action of the subterraneous waters. Such cavities, which are met with in all the sedimentary strata, are generally filled after their formation with new substances totally different from the surrounding rock. It is thus that masses of rock-salt are found in the Muschel-kalk and in the Marnes Irisées, fig. 45.

Similar masses of carbonate of zinc, as formed in the upper part of a stratum of transition limestone, are shown at C C, in fig. 30.

107. Since the memorable revolution effected by Bacon in the conduct of physical inquiries, a maxim has been universally admitted and adopted, in virtue of which, in the formation

of hypotheses for the explanation of natural phenomena, no cause can be admitted, except such as can be shown to have real existence, and which, being admitted, shall appear to be sufficient to produce the phenomena which it is put forward to explain. In accordance with this rule, geologists are therefore required to show

Fig 45.

that the elevated internal temperature of the globe, those upheavings and disruptions of land, those sedimentary deposits from water, those ejections of fluid and pasty matter from clefts and caverns, those abrasions of the solid crust by the corroding action of water, and its modifications by the action of the atmosphere, are severally real agencies still in visible operation, and producing effects similar in kind though different in degree from those ascribed to them in geology, and also that even the difference in degree, which must be admitted to be often very considerable, admits of satisfactory explanation.

Before, therefore, proceeding further in the exposition of the phenomena disclosed by the labours of geologists, we shall here pause for the purpose of showing the reality of the various physical causes to which geologists have ascribed the phenomena. We shall see that like phenomena have been, and still are, developed on the surface of the earth; and that the reasons why these agencies were more energetic at remote epochs than at present are sufficiently obvious.

108. It has been already very fully explained in our Tract on "Terrestrial Heat," that in descending deeper and deeper through the crust of the globe, the temperature continually rises; so that at a depth which forms a very insignificant fraction of the semidiameter of the globe, the materials which constitute it must have a temperature altogether incompatible with their continuance in the solid state,—a temperature, in short, which is above the point of fusion of the most refractory of these materials.

109. The superficial heat of the earth may be considered, therefore, to result from the combined effects of solar and internal heat. In the present condition of the globe, the effects of the

former are incomparably greater than of the latter; but it may be imagined that at earlier epochs, when the solid crust of the earth was much less thick, the internal heat produced upon the surface a much more powerful effect; so that the climates of all parts of the globe must have been much more elevated than at present. Numerous effects compatible with this reasoning have been discovered by the researches of geologists. Thus, the organic remains of animals and plants found in the sedimentary strata deposited at earlier epochs in the growth of the globe, are such only as could have lived in climates of a much more elevated temperature, than those which now characterise the latitudes in which they are found. Thus, the fauna and the flora (terms adopted by naturalists to express the entire collection of animals and plants existing in any place) prevailing in high latitudes at remote epochs, were such as could exist at present only within the tropics.

110. The alternate upheavings, depressions, disruptions, and dislocations of the crust of the earth assumed by geologists in their explanation of the phenomena are still exhibited, though

Fig. 46.

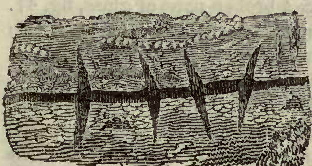


Fig. 47.

on a much smaller scale, in the phenomena attending earthquakes. These effects have been so fully explained in our Tract on "Earthquakes and Volcanoes," that little need be added to what has been there stated. As these phenomena are manifested at present, they are most frequently more or less local, though sometimes their effects are spread over little less than an entire hemisphere. The earthquake which took place in the island of Ischia, on the 2nd of February, 1828, was not felt in the slightest degree either in the neighbouring isles or upon the Continent; while that of New Grenada, which took place on the 17th of June, 1826, exercised its influence over many thousand square miles. The earthquake which commenced in Lisbon in 1755, and which has been fully described in a former Tract, extended in one direction to Lapland, and in the other to Mar-

tinique. It was sensible, also, at right angles to this direction, from Greenland to Africa, where the cities of Morocco, Fez, and Mequinez were destroyed by it. Its effects were manifested in all parts of Europe at the same moment.

111. These convulsions not only destroy entire cities and overturn the most solid edifices, but they are attended with important modifications in the levels of the ground. Those of Calabria, in 1783, supply remarkable examples of them, and are so much the more worthy of attention, as they were circumstantially described by several eminent men who were witnesses of the phenomenon, such as Vicencia, physician of the King of Naples, Grimaldi, Sir W. Hamilton, and by a commission of the Royal Academy of Naples. The whole extent of the country was convulsed, the beds of the rivers were changed, houses were, some raised above the general level, and others at short distances from them sunk below it; edifices of the greatest solidity were cracked in their walls, while certain parts of them were raised above others, and their foundations in many instances forced above the earth; crevices were formed in the ground, some of which measured five or six hundred feet in width; some were straight, some bifurcated; sometimes a single enormous cleft having a certain direction was intersected at right angles by a number of others, fig. 46; others were developed in clefts radiating from a centre, like a broken pane of glass, fig. 47. Some crevices laid open at the moment of a shock, and into which entire buildings had fallen, closed almost immediately again, crushing between their sides all that they had thus engulfed. In some cases the sides of the cleft were separated at the surface, but brought into contact with each other at a certain depth, figs. 48-9. In other cases, the parts disrupted merely sunk below the other without ceasing to be in contact, fig. 50.

Fig. 48.

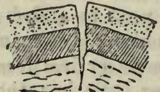


Fig. 49.

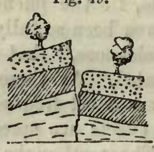


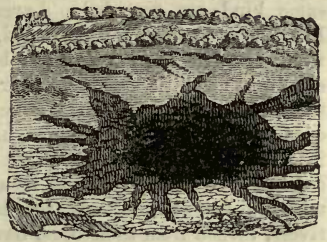
Fig. 50.

In other cases, the force which burst the superior crust was sufficient, not merely to split it into different clefts, but to produce in it a vast cavity, from the edges of which clefts diverged, fig. 51.

In some cases a considerable tract of ground was suddenly engulfed, carrying with it the plantations and buildings which

chanced to be upon it, and leaving nothing but a yawning gulf, with sides nearly vertical, from 300 to 400 feet deep. In some instances an immense quantity of water was collected in the cavities, and formed lakes more or less considerable in magnitude, some of which had no apparent issue, while the water from others flowed in enormous torrents. In other cases the contrary effects were manifested, rivers and lakes suddenly disappearing as if they had sunk into the bowels of the earth.

Fig. 51.



112. While the principal of these earthquakes upon the Italian peninsula was limited to the tract between Oppida and Soriano, the phenomena were propagated under the straits of Messina to that city, more than half of which, with twenty-nine surrounding towns and villages, was swallowed up. The bottom of the sea sunk, the shores were torn by clefts, and all the ground along the harbour of Messina was inclined towards the sea, sinking suddenly to the depth of some feet. The entire promontory by which the entrance to the harbour was formed, was swallowed up in an instant.

113. The earthquakes which took place on the coast of Chili in 1822—35—37, produced effects not less remarkable. Different parts of the coast from Valdivia to Valparaiso, an extent of more than 200 leagues, was manifestly raised above the water, as well as several adjacent islands extending to that of Juan Fernandez. The bottom of the sea, to a considerable distance, was similarly affected. Upon the coasts, rocks formerly covered with water, were raised eight or ten feet above the level of the sea, covered with the shells attached to them. Rivers, which emptied themselves at different parts of the coast, and which were navigable to vessels of small tonnage, became fordable. At sea, well known anchorages were diminished in depth; and various parts, where vessels formerly passed safely, were now complete shoals, inaccessible to vessels except those of the lightest draught.

114. Similar effects were manifested in India in 1819. A hill, 60 miles long, and 18 wide, extending from S.E. to N.W., was raised in the middle of a flat country, barring the course of the Indus. Further south, and in a parallel direction, the ground was sunk and with it the town and fort of Sindré, which remained, however, standing, though half submerged. The eastern embouchure

of the river became deeper at several places, and different parts of its bed, formerly fordable, ceased to be so.

115. In the records of all ages and countries, effects of the same kind are recorded. Large crevices in the earth have been formed, deep gulfs opened, into which cities, and even whole countries, have sometimes been swallowed up. From these openings, mephitic vapours, water in enormous quantities, sometimes cold, sometimes warm, have been ejected, and, occasionally, even flame has issued. Plains have been suddenly transformed into mountains, shoals produced in the deepest seas, mountains cracked and overturned, and mountainous tracts, many hundred miles in extent, suddenly levelled or replaced by deep lakes; rivers, turned from their beds, have discharged their waters into cavities thus formed; lakes, breaking through their banks, have been emptied, and their bottoms left dry, or have been turned through subterraneous openings suddenly formed beneath them. On the contrary, in some cases numerous springs, natural artesian wells, have been formed, supplying waters which suddenly issued from crevices of the rock or from tunnels. Thermal springs have been suddenly rendered cold, or altogether dried up, while others, on the contrary, have been produced where none existed.

All these, and many other phenomena, indicate the existence of internal convulsions, by which the matter subjacent to the crust of the earth is driven upwards through its crevices.

116. Independently of the phenomena of this class which are authentically recorded in history, many others are subjects of tradition. Thus, Pliny relates a tradition that Sicily had been separated from Italy, Cyprus from Syria, and Eubœa from Bœotia, by earthquakes. According to another classical tradition, a great island called Atlantis existed in ancient times west of the Straits of Gibraltar, having a numerous population. Its princes invaded Africa and Europe, but were defeated by the Athenians and their allies. Its inhabitants afterwards became wicked and impious, and the island was visited with the vengeance of the Gods, and swallowed up by the ocean in a single day and night. This legend is given by Plato, and is said to have been related to Solon by the Egyptian priests. According to all the analogies supplied by the phenomena described above, there is nothing impossible, or even improbable, in that part of this legend which refers to an island being engulfed by the ocean.

117. The cases in which the dry land has been invaded by the sea, or the bed of the sea left dry by the retirement of the waters, has been popularly, and even by the scientific of former days, ascribed to the change in the level of the waters of the ocean, their elevation producing inundations, and their fall leaving

tracts, formerly covered, dry. Considering the solid and apparently permanent character of the land on the one hand, and the extreme mobility of water on the other, such a conclusion was natural, and almost inevitable, until clear evidence of the contrary was obtained. It has, however, been proved that the very reverse has been the case of such phenomena, the mobility appertaining to the land, and the permanence to the sea. It has been shown, by observations made upon the level of the ocean, that it has not suffered any general change within historic times; but, on the contrary, that the cases in which the land has been inundated by the ocean must be ascribed to the sinking of the land, and those in which the waters have deserted their bed to the rising of the bottom of the sea.

118. These changes in the level of the crust of the earth have been in some cases sudden, as when they are produced by earthquakes, but in others they have been so gradual that they could only be ascertained by observation extending over long intervals of time. It had been long observed in different parts of Sweden, that the level of the surrounding ocean was subject to an apparent but slow and gradual change, in some places rising, in others falling. The Academy of Upsal, in 1731, commenced a series of observations with a view of determining the fact whether this apparent change of the ocean were real, or whether it were not caused by an actual change in level of the land. Marks were accordingly cut upon the faces of rocks at the level of the sea, and at the end of some years these marks were several inches above that level, from whence it was in the first instance inferred that the Baltic had suffered a depression of its level, so as to leave more or less of the bottom dry. These observations, however, being continued and multiplied, it was soon rendered apparent that, while the level of the Baltic remained unchanged, the phenomena were produced by actual changes in the level of the land. It was found that the apparent depression of the level of the ocean was different in different places, and that in some places, on the contrary, it appeared to have been even raised. Thus, while at certain points the apparent depression amounted to several inches, in others it did not exceed a fraction of an inch; at some places, such as the coast near Christianstad, the level of the sea appeared to be elevated. The conclusion deduced from all these observations was, that the apparent change of level of the sea was produced by a slow and gradual upheaving of the land in some places, and a sinking in others; that in Finland, and in a great part of Sweden, the surface was gradually raised without any perceptible shock, while in the southern parts of the peninsula a corresponding depression was produced.

119. Similar swellings and depressions of the land have been manifested elsewhere. Thus, for four centuries, the western coast of Greenland has been continually sinking through an extent of 600 miles north and south. Ancient buildings, as well upon the low islands of the coast as upon the mainland, have been gradually submerged, and the removal to considerable distances inland of various establishments which formerly existed upon the coast, has been rendered necessary. Similar sinkings of the surface have been manifested in certain islands of the Southern Ocean, especially in the Indian Archipelago.

120. It would even appear, from a comparison of the observations of Messrs. Boussingault and Humboldt, separated by an interval of thirty years, that the whole continent of South America is gradually sinking, and, if this process be continued, at some distant epoch it may even be submerged. The observations referred to show that the altitudes of the Andes at the epoch of the observations of Boussingault were less than those given by the anterior observations of Humboldt; and these results are confirmed by the fact that the snow-line in this range of mountains has, in the interval referred to, apparently risen.

121. An interesting modern example of the subsidence of a considerable tract of country, clothed with forests, the trees remaining erect, although submerged beneath a river which still flows over them, is described by a late American writer, and will serve to illustrate these remarks. The whole district, from the Rocky Mountains on the east, and the Pacific Ocean on the west, and from Queen Charlotte's Island on the north, to California on the south, presents one vast tract of volcanic formation. Basalt—both columnar, and in amorphous masses, veins, and dykes—everywhere occurs, and craters of extinct volcanoes are still visible. Elevations and dislocations of the strata have taken place on an immense scale; and successive beds of basalt, amygdaloidal trap, and breccia, prove the alternation of igneous action and periods of repose. Within a few miles of the falls of the river Columbia, and extending upwards of twenty miles, trees are seen standing in their natural position, in a depth of water from 20 to 30 feet. The trees reach to high or fresh-water mark, which is 15 feet above the lowest level of the tide; but they do not project beyond the freshet rise, above which their tops are decayed and gone. In many places the trees are so numerous, that "we had to pick our way with the canoe, as through a forest. The water of the river was so clear, that the position of the trees could be distinctly seen, down to their spreading roots, and they are standing as in their natural state, before the country had become

submerged. Their undisturbed position proves that the subsidence must have taken place in a tranquil manner." *

122. Another most interesting and remarkable example of the alternate elevation and depression of the surface of the earth, manifested within historic times, is presented in the case of the ground upon which the temple of Jupiter Serapis stands, at Pozzuoli, near Naples. These ruins, standing on the northern shore of the Bay of Baiæ, at a short distance from the Solfatara, consist of the remains of a large building of quadrangular form, 70 feet in diameter, the roof of which was originally supported by 46 columns, 24 of which were granite, and 22 marble, each column consisting of a single stone. Many of these pillars are broken, and their fragments strewn about the pavement, but three of them still remain standing (fig. 52). Their base is near the level of the sea. The surface of the columns, the tallest of which is 42 feet in height, is smooth up to an elevation of 12 feet from the pedestal, where a band of perforations 9 feet wide commences, made by a species of mussel, called the *Modiola lithophaga*, which could only have lived in sea-water. Above this band, at the height of 21 feet from the pedestal, these cavities are discontinued, and the remainder of the pillars are smooth, like the lower part. The cavities, many of which still contain shells, sand, and microscopic shields, are of elongated elliptical shapes, and so numerous and deep as to prove that the pillars must have been submerged in sea-water to a height more or less above the limit of these borings, for a long period of time. The lower part of the columns, which are not similarly affected, must have been protected, while they were submerged, from the depredations of these boring mussels by surrounding accumulations of rubbish and tufa, while the upper parts projected above the water, and were consequently beyond the reach of these animals.

The platform of the temple is now about one foot below high-water mark, and the sea, which is only 40 yards distant, penetrates the intervening soil. The upper part of the band of perforation is at least 23 feet above the level of the sea.

It appears from all this, that the ground on which the temple stands must have changed its level more than once, being alternately heaved upwards and downwards. It is clear that when the temple was built, the ground of its foundation must not only have been high and dry, but remote from the shores of the bay, and at some subsequent period must have sunk gradually, and so

* Journal of an Exploring Tour beyond the Rocky Mountains, by the Rev. Samuel Parker, A.M. New York, 1838.

tranquilly as not to overturn the columns, to a depth above the band of perforation, and at a still more recent period must have again been raised to its present level.

123. It results from the researches of Professor Forbes upon this subject, that historical evidence is extant illustrating the respective dates of these changes of level. From inscriptions recording the embellishment of the temple by Septimius Severus (A.D. 193—211), and Marcus Aurelius (A.D. 161—180), it appears that the building was still entire, and occupied its present position at the close of the second and commencement of the third century; that in A.D. 1198, the eruption of the volcanic lake of Solfatara took place, attended with earthquakes, and a general subsidence of the coast ensued, which caused the temple to sink to a depth which submerged its columns in water to a height above the band of perforations. In this state it appears to have continued until the commencement of the sixteenth century; for the flat district called La Starza, in which the building stands, is described by contemporary observers as being covered by the sea in 1530. Eight years later, frequent and violent earthquakes prevailed along all that part of the Neapolitan coast; and on the 29th of September in that year, the volcanic eruptions burst forth which threw up the Monte Nuovo already described. During this catastrophe the coast on the north of the Bay of Baiæ was permanently raised 20 feet, forming a tract 600 feet in breadth, and including the area in which—

> "Those lonely columns stand sublime,
> Flinging their shadows from on high,
> Like dials, which the wizard Time
> Had raised to count his ages by!"—MOORE.

These were accordingly left above the water, several of the columns still retaining their original position. They seem to have been wholly neglected by antiquaries till 1750, when the shrubs and weeds with which they were overgrown and concealed were removed, and the earth accumulated in the court of the temple cleared away. For the last thirty or forty years a slow subsidence of the coast appears to have been going on, and the floor of the temple is often submerged.*

124. We are not informed whether the Irish tradition, reproduced by Moore so beautifully in the following lines, has been verified by any scientific observers; but, if so, it would seem as

* See a paper by Professor Forbes on the subject in Brewster's "Journal of Science," vol. i. second series; and also a letter quoted by Dr. Mantell, and addressed to him by M. Hullmandel, "Wonders of Geology," vol. i. p. 458.

though Lough Neagh were the result of a post-Adamite sinking of the ground.

> "On Lough Neagh's banks as the fisherman strays,
> When the clear cold eve's declining,
> He sees the round towers of other days
> In the wave beneath him shining!
>
> Thus shall memory, often, in dreams sublime,
> Catch a glimpse of the days that are over;
> Thus, sighing, look through the waves of time
> For the long faded glories they cover!"—MOORE.

125. It appears, then, that the crust of the earth, instead of being endowed with that character of stability and immobility popularly ascribed to it, is subject to incessant as well as occasional upheavings and depressions. It may indeed be regarded as in a certain degree elastic, yielding to the undulations, whether slow and gradual, or sudden and more violent, of the agencies within it.

Such phenomena, however, will cease to astonish when we reflect what an enormous disproportion exists between the thickness of the solid crust of the globe, and the mass of matter in a state of igneous fusion which it encloses; the crust being relatively thinner than a piece of card-board attached to the rind of an orange, it cannot be matter of surprise that it should be subject to more or less derangement of form, and even occasional disruption, by the action of the fluid matter within it. That such changes and such disruptions and their consequences should be much more considerable at earlier than at more recent epochs, is also a natural consequence of the growth of the crust of the globe by the process of cooling. The earlier the epoch the thinner that crust must have been, and the less its resistance to internal force. Forces which would now fail to produce any sensible effect upon its form, would at those earlier epochs have been sufficient to disrupt it. That such effects have been actually produced at various geological epochs is proved by the most incontrovertible evidence presented by the crust of the globe itself, as will presently be more fully explained. Volcanic phenomena are closely connected with those of earthquakes, and, like them, supply analogies by which various geological phenomena are explained.

126. When the crust of the earth is disrupted in the manner explained above, openings are made in it which supply communication between its internal fluid nucleus and its external surface, and through these openings matter of various forms is often ejected with vast force. The matter thus ejected consists sometimes of the disrupted and broken parts of the crust itself, which are projected upwards, vertically or obliquely as the case may be,

and often scattered over the surrounding country to vast distances. Sometimes the matter thus thrown up is in a state of pasty fusion, and is incandescent, scoriaceous, and pumiceous. In this semi-fluid state it is projected sometimes to a distance, and sometimes it flows in streams along the slopes of declivities, or collects in a sheet or layer of more or less thickness round the crater from which it is ejected.

127. These volcanic phenomena have been already, in part, explained in our Tract on Earthquakes and Volcanoes, but their connection with the condition and history of the crust of the earth is so close, and the aids they afford for the explanation of geological phenomena so important, that it will be necessary here further to enlarge upon them.

In the month of May, 1808, the ground in the island of San Jorge, one of the Azores, in the midst of an open plain and cultivated fields, was suddenly upheaved, after which it cracked at several places with a terrific noise. A vast cavity or crater was formed in the middle of it, having an area of nearly thirty acres, and surrounded within the distance of three miles by from twelve to fifteen smaller craters. An enormous quantity of scoriaceous and pumiceous matter was projected from it which covered the surrounding ground to the depth of five feet for an extent of twelve miles in length by three in breadth. Streams of molten matter issued from it, which continued to flow for more than three weeks from the principal crater to the sea.

128. The Monte Nuovo, which was formed upon the Neapolitan coast in the Bay of Baiæ in 1538, presents an example of like phenomena. A violent earthquake had prevailed for two years, which, on the 27th and 28th of September, 1538, suddenly increased so as to be attended with incessant movement of the ground day and night. The plain extending between the Lake of Averno (the ancient Avernus), the Monte Barbaro and the sea was then suddenly upheaved, and various crevices were formed in it; the ground, rising still more, assumed the form of a mountain. During the succeeding night, the summit of this mountain opened with prodigious noise, and vomited great masses of flame, accompanied by pumice stones and ashes. The eruption continued for seven days, the matter ejected filling up the Lucrine Lake. Since this eruption the most perfect tranquillity has continued at this place.

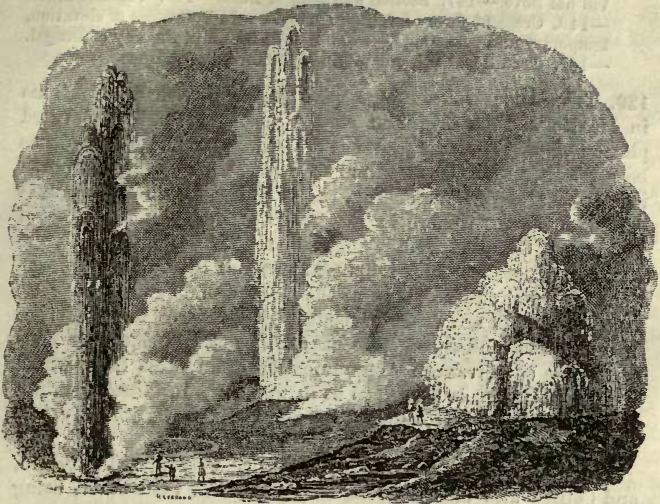


Fig. 71.—THE GEYSERS, ICELAND.

THE CRUST OF THE EARTH;

OR, FIRST NOTIONS OF GEOLOGY.

CHAPTER V.

129. Volcanoes of the Andes—Pichincha, Cotopaxi, and Tunguragua.—130. Mexican volcanoes—Orizaba, Popocatapetl, Jorullo, and Colima. 131. Singular circumstances attending the elevation of Jorullo.—132. Ancient state of Vesuvius, according to Strabo—Eruption of 76 A.D.—Destruction of Herculaneum and Pompeii.—133. Volcano of Kirauea in Owhyhee—Mr. Ellis's account of it.—134. Visit of Mr. Stewart and Lord Byron to it in 1825—Mr. Stewart's account of it.—135. Illustrations of the ejection of lava through the strata.—136. Effect of obstruction—formation of lateral craters.—137. Submarine eruptions—Formation of volcanic islands.—138. Volcanic islands off Santorin, in the Grecian Archipelago.—139. Phenomena attending the formation of such islands.—140. Craters of elevation.—141. Stratification around these craters—Island of Palma.—142. Formation of islands not necessarily preceded by eruptions.—143. Mount Etna.—144. Historical accounts of its eruptions.—145. Eruption of 1832.—146. The

Val del Bove.—147. Section and plan of Etna.—148. Volcanic lakes.—149. Crescent form of volcanic islands.—150. Craters of elevation, temporary and permanent.—151. Barren island in the Bay of Bengal.—152. Traditional volcanic origin of Santorin.

129. The famous volcano of Jorullo in the Anahuac mountains in Mexico had its origin in similar phenomena. The elevated plateau which forms the province of Quito, in South America, has been the theatre of extraordinary volcanic phenomena. Beneath it is a focus of volcanic energy, the channels of which communicate with the atmosphere by the craters of the great volcanoes of Pichincha, Cotopaxi, and Tunguragua, part of the chain of the Andes. These, by their groupings as well as by their lofty elevation and grand outlines, present the most sublime and picturesque aspect which is anywhere concentrated within so small a space in a volcanic landscape. The extremities of the chain are connected by subterranean communications; and this fact, which experience has made known to us in numerous instances, reminds us of the old and just statement of Seneca, that the crater is only the issue of more deeply-seated volcanic forces.

130. The Mexican volcanoes of Orizaba, Popocatapetl, Jorullo, and Colima also appear to be connected with each other, being placed in the direction of a line running transverse to the former, and passing east and west from sea to sea.

131. As was first observed by Humboldt, these mountains are all situated between north latitude 18° 59′ and 19° 12′. In an

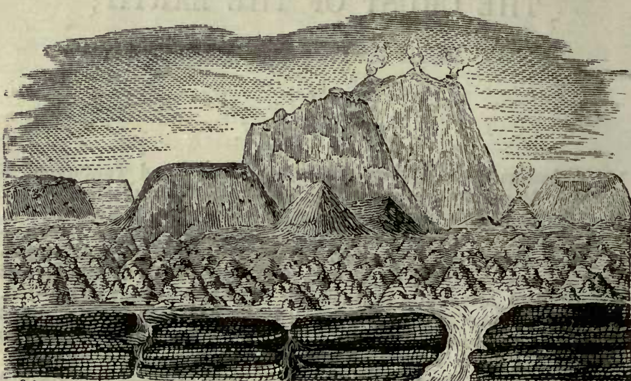


Fig. 53.—Volcano of Jorullo, Mexico.

exact line of direction with the other volcanoes, and over the same transverse fissure, Jorullo was suddenly elevated on the

29th of September, 1759. The circumstances attending the production of this volcano are so remarkable, that we shall here notice them in some detail.*

An extensive plain, called the Malpays, was covered by rich fields of cotton, sugar-cane, and indigo, irrigated by streams, and bounded by basaltic mountains, the nearest active volcano being at the distance of eighty miles. This district, situated at an elevation of about 2600 feet above the level of the sea, was celebrated for its beauty and extreme fertility. In June, 1759, alarming subterranean sounds were heard, and these were accompanied by frequent earthquakes, which were succeeded by others for several weeks, to the great consternation of the neighbouring inhabitants. In September tranquillity appeared to be re-established, when, in the night of the 28th, the subterranean noise was again heard, and part of the plain of Malpays, from three to four miles in diameter, rose up like a mass of viscid fluid, in the shape of a bladder or dome, to a height of nearly 1700 feet; flames issued forth, fragments of red-hot stones were thrown to prodigious heights, and, through a thick cloud of ashes, illumined by volcanic fire, the softened surface of the earth was seen to swell up like an agitated sea. A huge cone, above 500 feet high, with five smaller conical mounds, suddenly appeared, and thousands of lesser cones (called by the natives *hornitos*, or ovens,) issued forth from the upraised plain. These consisted of clay intermingled with decomposed basalt, each cone being a *fumarolle*, or gaseous vent, from which issued thick vapour. The central cone of Jorullo is still burning, and on one side has thrown up an immense quantity of scoriaceous and basaltic lavas, containing fragments of primitive rocks. Two streams, of the temperature of 186° of Fahrenheit, have since burst through the argillaceous vault of the hornitos, and now flow into the neighbouring plains. For many years after the first eruption, the plains of Jorullo were uninhabitable from the intense heat that prevailed.†

132. It appears that the cone from which Vesuvius takes its present character has been the result of similar effects.

In the description of the mountain given by Strabo, no mention whatever is made of the cone which now forms its most remarkable feature. The slopes of the mountain, says Strabo, were regions of the greatest fertility; its summit was truncated, entirely sterile, and had a burnt aspect, displaying cavities full of crevices and calcined stones, from which it must be conjectured that they had been formerly volcanic craters. It seems, therefore, that the cone to which the name of Vesuvius now more

* Cosmos, vol. i. p. 229. Trans.

† Mantell, p. 837.

properly belongs, and of which all the products differ altogether from the rocks of the semicircle called the *Somma* which existed in ancient times, was not formed until a much more recent period, and probably dates from the famous eruption of the year 76 A.D., which was signalised by the loss of Pliny. It was then, probably,

Fig. 54.—Vesuvius as now formed.

Fig. 55.—Vesuvius in the time of Strabo.

that a permanent communication was opened between the crater and the internal parts of the earth. This catastrophe appears to have produced but little lava, although it was attended with violent effects on the surrounding country, throwing a great part of the mountain into the sea, and burying Herculaneum and Pompeii, not, as is vulgarly supposed, under molten matter ejected from the crater, but under avalanches of pumiceous substance, which existed previously upon the slopes of the mountain.

133. Of all existing volcanoes, that of Kirauea, in Hawaii, one of the Sandwich Islands, better known under the popular name of Owhyhee, and noted as the theatre of the murder of Captain Cook, exhibits volcanic phenomena under their most sublime and imposing aspect. The island of Hawaii, which is about seventy miles long, and covers an area of 4000 square miles, is a complete mass of volcanic matter, perforated by innumerable craters. It is, in fact, a hollow cone, rising to an altitude of 16000 feet, having numerous vents over a vast incandescent mass, which doubtless extends beneath the bed of the ocean, the island forming a pyramidal funnel from the fluid nucleus beneath to the atmosphere. The following graphic account of a visit to the crater, by Mr. Ellis, affords a striking picture of the splendid, but awful, spectacle which this volcano presents.

"After travelling over extensive plains and climbing rugged steeps, all bearing testimony of igneous origin, the crater of Kirauea suddenly burst upon our view. We found ourselves upon the edge of a steep precipice, with a vast plain before us fifteen or sixteen miles in circumference, and sunk from two to four hundred feet below its original level. The surface of this plain was uneven, and strewed over with large stones and volcanic rocks; and in the centre of it was the great crater, at the distance of a mile and a half from the precipice on which we were standing, We proceeded to the northern end of the ridge, where, the sides being less steep, a descent to the plain below seemed practicable;

but it required the greatest caution, as the stones and fragments of rocks frequently gave way under our feet, and rolled down from above. The steep which we had descended was formed of volcanic matter, consisting apparently of light red and grey vesicular lava, lying in horizontal beds, varying in thickness from one to forty feet. In a few places the different masses were rent in perpendicular and oblique directions, from top to bottom, either by earthquakes, or by other violent convulsions of the ground. After walking some distance over the plain, which in several places sounded hollow beneath our feet, we came to the edge of the great crater. Before us yawned an immense gulf in the form of a crescent, about two miles in length from the north-east to south-west, one mile in width, and 800 feet deep. The bottom was covered with lava, and the south-west and northern parts were one vast flood of burning matter. Fifty-one conical islands of varied form and size, containing as many craters, rose either round the edge or from the surface of the burning lake. Twenty-two constantly emitted either columns of grey smoke or pyramids of brilliant flame, and at the same time vomited from their ignited mouths streams of lava, which rolled in blazing torrents down their black indented sides into the boiling mass below. The existence of these conical craters led us to conclude that the boiling cauldron of lava did not form the focus of the volcano, but that this liquid mass was comparatively shallow, and the basin which contained it separated by a stratum of solid matter from the great volcanic abyss, which constantly poured out its melted contents through these numerous craters into this upper reservoir. We were further inclined to this opinion from the vast columns of vapour continually ascending from the chasms in the vicinity of the sulphur banks and pools of water, for they must have been produced by other fire than that which caused the ebullition in the lava at the bottom of the great crater; and also by noticing a number of small vents in vigorous action high up the sides of the great gulf, and apparently quite detached from it. The streams of lava which they emitted rolled down into the lake, and mingled with the melted mass, which, though thrown up by different apertures, had perhaps been originally fused in one vast furnace. The sides of the gulf before us, although composed of different beds of ancient lava, were perpendicular for about 400 feet, and rose from a wide horizontal ledge of solid black lava, of irregular width but extending completely round. Beneath this ledge the sides sloped gradually towards the burning lake, which was, as nearly as we could judge, three or four hundred feet lower. It was evident that the large crater had been recently filled with liquid lava up to this ledge, and had, by some subterranean

channel, emptied itself into the sea, or upon the low land on the shore; and in all probability this evacuation had caused the inundation of the Kapapala coast, which took place, as we afterwards learned, about three weeks prior to our visit. The grey, and in some places apparently calcined sides of the great crater before us—the fissures which intersected the surface of the plain on which we were standing—the long banks of sulphur on the opposite sides of the abyss—the vigorous action of the numerous small craters on its borders—the dense columns of vapour and smoke that rose out of it, at the north and south ends of the plain, together with the ridge of steep rocks by which it was surrounded, rising 300 or 400 feet in perpendicular height—presented an immense volcanic panorama, the effect of which was greatly augmented by the constant roaring of the vast furnaces below." *

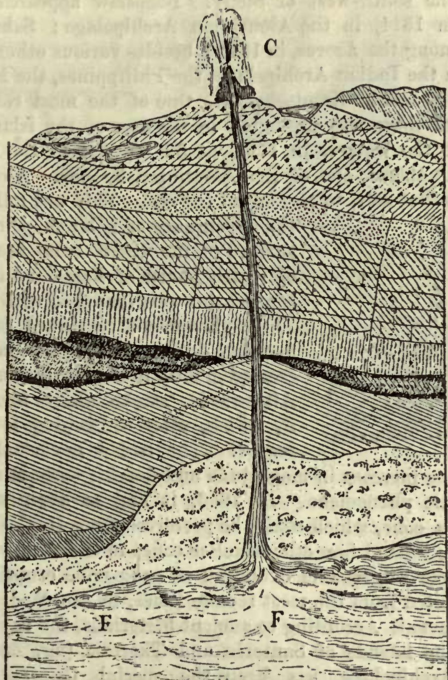
134. This volcano was also visited in 1825 by Mr. Stewart, accompanied by Lord Byron and a party from the "Blonde" frigate, who descended to the bottom of the crater. Mr. Stewart has left the following description of it:—"The general aspect of the crater," observes he, "may be compared to that which the Otsego Lake would present, if the ice with which it is covered in winter were suddenly broken up by a heavy storm, and as suddenly frozen again, while large slabs and blocks were still toppling, and dashing and heaping against each other, with the motion of the waves. At midnight the volcano suddenly began roaring, and labouring with redoubled activity, and the confusion of noises was prodigiously great. The sounds were not fixed or confined to one place, but rolled from one end of the crater to the other; sometimes seeming to be immediately under us, when a sensible tremor of the ground on which we lay took place; and then again rushing on to the farthest end with incalculable velocity. Almost at the same instant a dense column of heavy black smoke was seen rising from the crater directly in front, the subterranean struggle ceased, and immediately after flames burst from a large cone, near which we had been in the morning, and which then appeared to have been long inactive. Red-hot stones, cinders, and ashes, were also propelled to a great height with immense violence; and shortly after, the molten lava came boiling up, and flowed down the sides of the cone and over the surrounding scoriæ, in most beautiful curved streams, glittering with a brilliancy quite indescribable. At the same time, a whole lake of fire opened in a more distant part. This could not have been less than two miles in circumference, and its aspect was more horribly

* Ellis's Polynesian Researches, vol. iv.

sublime than anything I ever imagined to exist, even in the ideal visions of unearthly things. Its surface had all the agitation of the ocean; billow after billow tossed its monstrous bosom into the air, and occasionally those from different directions burst with such violence, as in the concussion to dash the fiery spray forty or fifty feet high. It was at once the most splendid and fearful of spectacles."

135. The manner in which the liquefied matter is driven upwards through the superjacent crust of the earth, and ejected from the crater is illustrated in fig. 56, where F F represents

Fig. 56.



the fluid nucleus of the globe, and F C the passage along which the fluid matter has burst its way through the successive strata to the crater from which it issues.

136. It sometimes happens that the passage, through which it is thus forced in the first instance becomes obstructed, so

that the escape of the lava through it is intercepted. In such cases the pressure of the fluid matter acting against the walls of the cleft, or channel, breaks through them at one or more points of least resistance, and new issues are formed on another side of the original crater. These lateral craters may also be produced, even though the central crater is still in activity (fig. 57).

137. Volcanic eruptions are not confined to the land, but are often produced in the bed of the ocean. In such cases islands often rise suddenly out of the bottom of the deep. Thus, in 1831, the island of Julia arose in the Mediterranean, about 30 miles to the south-west of Sicily. Bogoslaw appeared in like manner, in 1814, in the Aleutinian Archipelago; Sabrina and another among the Azores, in 1811; besides various others around Iceland, in the Indian Archipelago, the Philippines, the Moluccas, and off the coast of Kamtschatka. One of the most remarkable examples of these was presented in the case of the island which rose above the waters, in 1796, at 30 miles from the northern point of Unalaska, one of the Aleutinian islands. A column of smoke was first seen to rise out of the sea. This was followed by the appearance of a black point at the surface of the water, from the summit of which blades of flame and incandescent matter were launched with violence. These phenomena continued for several months, during which the island increased greatly in magnitude and height. Afterwards, smoke alone issued from it, which, after continuing four years, ceased. The island nevertheless, still continued to increase in magnitude and height, without manifesting volcanic phenomena. In 1806, it had so augmented that it formed a cone, which could be perceived from Unalaska, upon which were formed four other smaller cones in the north-west side.

Fig. 57.

138. Some remarkable examples of submarine eruptions have been presented from the most remote times, in the Mediterranean and the Levant. According to ancient historians, the bay included between the islands of Santorin and Theresia (fig. 58), in the Grecian Archipelago, has been the special theatre of these phenomena. The island of Santorin is a half-moon-shaped tract of land, evidently of volcanic origin, and the islands of Theresia and Aspronisi, extending between the horns of the crescent, enclose the bay. Within this enclosure, the island of Hiera rose above the water in 186 B.C., and round it, and close to its coast several islets appeared in 19 A.D., 726 A.D., and 1427 A.D. In

1573 A.D., appeared the large island called Micra Kamini, and in 1707, the still larger one, Nea Kamini. The latter underwent a gradual increase of magnitude during several succeeding years.

Fig. 58.

No volcanic crater was formed upon these islands, which appear to cover the orifices in the subjacent crust through which the liquid matter which forced them up acted.

139. These submarine volcanic phenomena are generally preceded by incandescent matter thrown above the waters, by scoriaceous and pumiceous matter appearing on the surface, by burning rocks which appear in the midst of vaporous waves, and by the ebullition of the sea, the temperature of which then becomes very elevated. All these effects were manifested in modern times in the appearance of the islands of Julia, Sabrina, and others, and the more ancient phenomena are similarly described in historic narratives.

The circumstances attending them, however, are not always identical. Sometimes no solid rock is raised above the water. Thus, for example, at Kamtschatka, in 1737, jets of vapour only were thrown up. Great ebullitions of the sea took place, and pumiceous matter flowed on the surface. On the subsidence of the eruptions, it was found that chains of submarine mountains had been formed where previously there was a depth of 100 fathoms. In other cases there are not even jets of vapour, and the phenomenon is manifested only by the increased temperature

of the waters, and by the sudden elevation of the matter which existed at the bottom of the sea. This took place in 1820 at the island of Banda in the Moluccas, where the bay, which previously had a depth of 50 fathoms, was elevated by the tranquil upheaving of compact basaltic matter which previously existed there, and which formed a promontory composed of large blocks piled one upon the other, without any accessory phenomena except the increased temperature of the waters.

It has been ascertained also that violent submarine eruptions are often followed by slow and gradual upheavings of the bottom of the sea. This effect was manifested in the case of the island near Unalaska, and also in those produced near Santorin. It may be added also, that the islands thus produced are not always permanent; many of them disappear after intervals of more or less duration, being either swept away by the water or sinking into abysses formed under them.

140. Volcanic craters, which result from the upheaving of the crust of the earth in places where no volcano previously existed, are distinguished by the name of CRATERS OF ELEVATION, from those craters which break out at different points in existing volcanoes. In like manner, the conical mounds similarly formed are called cones of elevation. Craters of elevation are distinguishable even in places where no record or tradition of eruption exists, by the arrangement of the strata elevated, which is altogether dissimilar from what is found elsewhere. These strata are always inclined in all directions round the axis of the cone, as shown in fig. 59, presenting their edges abruptly towards the centre of the cavity. The Monte Nuovo, already mentioned, presents an example of this upon a small scale. The same formation is presented in the case of the semicircular Somma of Vesuvius.

141. Another characteristic, not less important, and especially useful for geological purposes in cases where the matter elevated is not stratified, is supplied in all great craters of elevation by the crevasses which extend from the borders of the crater to the external base of the mountain, and which are presented in so remarkable a manner in the Canaries, where they are called Barancos. These radiating crevasses are admirably shown upon the plan of the island of Palma, one of the Canaries, drawn by M. de Buch.

Fig. 59.

One of these Barancos, much deeper than the others, extends from the foot of the mountain, at a place called Tazacorte, to the base of the crater, as shown in the plan, and which is rendered still more apparent in the perspective view shown in fig. 61.

The volcanic islands which have arisen out of the ocean have assumed forms, all of which are analogous to those here described.

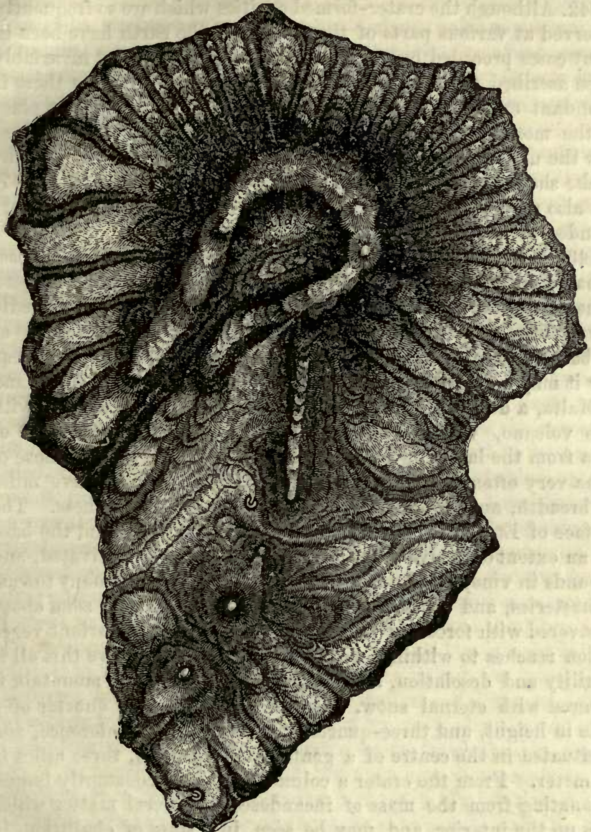


Fig. 60.—Plan of the island of Palma, one of the Canaries.

Thus for example, the island of Sabrina, at the moment of its

Fig. 61.—Perspective view of Palma.

appearance, took the form of a crater which had an opening to

the south, and which was terminated by crevasses from which boiling-water issued.

142. Although the crater-formed cavities which are so frequently observed at various parts of the surface of the earth have been in many cases preceded by volcanic eruptions, they are not invariably to be ascribed to that cause, and indeed in many cases there is abundant evidence that no such eruption could have taken place at the moment of their formation. We have already explained how the upheaving of the crust of the earth, produced by an earthquake shock, can produce not only radiating clefts, as in fig. 47, but also an open cavity, as in fig. 51, the edges of which are surrounded by divergent clefts.

143. Mount Etna, the most remarkable of European volcanoes, situated on the island of Sicily, and composed entirely of erupted mineral substances, rises to a height above the level of the Mediterranean of nearly eleven thousand feet. The circumference of its base is more than a hundred and eighty miles, and on a clear day it may be distinctly seen from any elevated point of the island of Malta, a distance of a hundred and fifty miles. Compared with this volcano, Vesuvius is insignificant. While the streams of lava from the latter never exceed seven miles in length, those of Etna very often are from fifteen to thirty miles, being five miles in breadth, and from fifty to a hundred feet in thickness. The surface of Etna presents three distinct regions. Around the base for an extent of twelve miles, the country is richly cultivated, and abounds in vineyards and pastures, and is the site of many towns, monasteries, and villages. The middle or temperate zone above is covered with forests of oak and chestnut, and a luxuriant vegetation reaches to within a mile of the summit. Above this all is sterility and desolation, and the highest point of the mountain is covered with eternal snow. The crater is about a quarter of a mile in height, and three-quarters of a mile in circumference, and is situated in the centre of a gently inclined plain, three miles in diameter. From the crater a column of vapour constantly issues, emanating from the mass of incandescent mineral matter which fills up the interior, and may be seen, in a state of ebullition, in the fumarolles in some of the lateral crevices, of which there are generally several accessible.

144. Etna is recorded as having been in a state of activity before the Trojan war; and ever since, at varying intervals, violent eruptions have occurred. In an eruption of 1669, the torrent of lava inundated a space of fourteen miles in length, and four in breadth, burying beneath it five thousand villas and other habitations, with part of the city of Catania, and at length falling into the sea. During several months before the lava burst

out, the old mouth, or great crater, was observed to send forth more smoke and flame than usual, and the top fell in, so that the cone became much lowered.

In 1809, twelve new craters opened, about half-way down the mountain, and threw out rivers of burning lava, by which several estates and farms were covered to the depth of thirty or forty feet; and in 1811, other vents appeared on the eastern side, and discharged torrents of liquid lava with amazing force.

145. In 1832, a violent paroxysm took place, and continued with but little intermission for several weeks. On the 31st of October, in the middle of the night, there arose, without any previous indication, a column of smoke and flame from the base of the large cone on the northern side; and, shortly after, an immense quantity of fluid matter was discharged from the crater, on the western side, divided into numerous streams. Next morning, repeated earthquakes, the increased noise of the lava, which now flowed rapidly, and the immense volumes of thick black smoke at the foot of Monte Scavo, announced that the eruption had greatly increased in violence, and several streams of lava were seen descending. On the 2nd of November, contrary to all expectation, the eruption ceased, and the lava was found to be so far cooled, that several adventurous observers were enabled to get upon it, and walk a few paces. On the 3rd, the hope that the fire was almost extinct was nearly certain; but in the evening, a violent earthquake, followed by several others less violent, with an increased quantity of smoke, foreboded an eruption; and two hours before midnight, another severe shock occurred, and was succeeded by black smoke mingled with flames, and incessant thunder.

"Having approached," says Signor di Luca, "as nearly as was prudent, to the hollow from which the fire issued, we found four apertures, which threw out burning matter. Raising our eyes from these vents, we observed a cleft or rent, about a mile in length, from which volumes of smoke arose from time to time; and, as at the bottom it reached the openings above-mentioned, it enabled us to behold the burning furnace in the interior of the mountain. Meanwhile the thunder was incessant, and the detonations were terrible; the lava continued to flow, and enormous masses of red hot substances were thrown to a great height mingled with vast volumes of flame and smoke. The shocks of earthquake were likewise so violent, that horses and other animals fled in terror from the places where they were feeding."

146. But by far the most interesting feature of Etna is an immense depression or excavation on the eastern side of the mountain, called the *Val del Bove*. This vast plain, or rather circular hollow, is five miles in diameter, and from two to three thousand

feet in the height of its bounding precipices, which in most places are nearly perpendicular. This remarkable area appears to have resulted from the giving way and subsidence of part of the crust of the volcano, from some violent action in the interior, which occasioned the sudden removal of an enormous mass of mineral matter. This plain is encircled by subordinate volcanic mountains, some of which are covered by forests, while others are bare and arid like many of the cones of Auvergne. The walls or cliffs surrounding this depression are formed of successive layers of lava of variable thickness, with interposed beds of tufa, ashes, and igneous conglomerates of different colours and degrees of fineness. They slope downwards towards the sea at an angle of from twenty to thirty degrees, and have evidently been formed at various intervals by successive eruptions from the top of the mountain, and were continuous before the subsidence took place which gives this region its present character.

The perpendicular sides of this natural amphitheatre are everywhere marked by vertical walls or dykes, which not only intersect the concentric sheets of lava and tufa, but, standing out in bold relief, like prodigious buttresses, impart a most extraordinary character to the scene; the greater induration of these intruded dykes having enabled them to resist the denuding action which has removed the less coherent pre-existing erupted materials. These buttresses are from two to twenty feet in thickness, and being of immense height, are extremely picturesque; some of them are composed of trachyte, and others of blue compact basalt with olivine. The surface of the plain is wild and desolate in the extreme, presenting the appearance of a tempestuous sea of liquid lava, suddenly congealed. Innumerable currents of lava are seen piled one upon the other, some of which terminate abruptly, while others have extended across the Val, and descended in cascades into the lower fertile regions, where they are spread out in sterile tracts amid the vineyards and orange groves.*

147. A section of Mount Etna, extending north and south between Catania on the south, and Taorminia on the north, is

Fig. 62.—Mount Etna.

shown in fig. 62; the east, upon the slope of which the cavity in question is observable, being presented to the observer.

* See Captain Basil Hall's graphic description of a visit to the Val del Bove, "Patchwork," vol. iii. p. 31.

A ground-plan of the Val del Bove and the surrounding parts of the mountain is shown in fig. 63.

Fig. 63.—Plan of the Val del Bove, Mount Etna.

148. The sudden sinking of the ground by which these crater-formed cavities are produced, is often attended with the sudden production of lakes, filling such cavities with water from subterranean sources. Such lakes are sometimes supplied with water at a high temperature, as was the case in one produced in 1835 in Cappadocia, near the ancient Cæsarea, and in 1820 in the island of St. Michael, one of the Azores.

149. Volcanic islands generally are found to affect the semilunar form, of which Santorin, fig. 58, is an example. Thus the island of Sabrina, already mentioned, which appeared in 1811 among the Azores, at the moment of its rise above the waters presented a crater which opened towards the south and was terminated by crevasses, or openings, from which issued a current of boiling water, figs. 64 and 65.

The island of Julia, which appeared to the south-west of Sicily in 1831, assumed a similar form, and on the 6th of September, 1835, Captain Thayer, the French navigator, found to the north of New Zealand a similar rock recently formed near the surface of the water, which included a lagoon, having a single issue, and within which the water was boiling.

150. These craters of elevation have sometimes continued permanently in the form which they first assumed, but they have also frequently been subject to subsequent changes of form from age to age. The case of Vesuvius, which underwent a remarkable change in 79 A.D., has been already mentioned. The Peak of Teneriffe rises within a circular enclosure, the sides of which are vertical, and rise to a height of from twelve hundred to two

thousand feet. The volcano of Taal, in the island of Lucon, one of the Philippines, is placed in the centre of a basin filled with

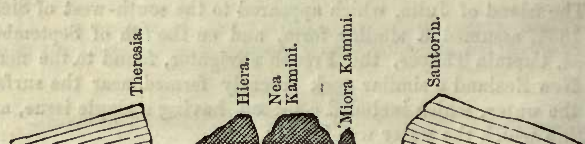
Fig. 64. Forms of volcanic islands. Fig. 65.

water and surrounded by steep and elevated rocks, which leave a single issue from it as in the cases already described.

151. A similar example of this form is presented in the case of Barren Island in the Bay of Bengal (fig. 66, p. 65), which consists of a circle of high mountains, into which the sea flows through a single opening, and of which the centre is occupied by a volcano two thousand feet high, which was in full activity at the time of the discovery of the island.

152. The islands of Santorin and Theresia, already described, form probably the borders of vast craters of elevation. Ancient historians cite them as having appeared long before the Christian era, after a succession of violent earthquake shocks, and in accordance with this tradition, they present strata inclined outwards, as shown in fig. 67; the islands more recently elevated

Fig. 67.



having issued from the middle of the crater. The strata observed in Santorin and Theresia, are inclined from the centre in accordance with the principle explained in (140).

Fig. 72.—THE SALSES, OR MUD VOLCANOES, OF CARTHAGENA.

THE CRUST OF THE EARTH;

OR, FIRST NOTIONS OF GEOLOGY.

CHAPTER VI.

153. Form of craters.—154. Stromboli—Formation of internal adventitious cones and craters.—155. Strata of lava—how formed.—156. Formation of lava n dykes.—157. Salses, or mud volcanoes.—158. Fumarolles.—159. Geysers.—160. Valleys of elevation.—161. Formation of parallel ridges.—162. Slow operation of air, water, and heat.—163. Atmospheric effects upon rocks.—164. Effects of water on rocks.—165. Effects of the sea on cliffs.—166. Effects of waterfalls.—167. Effects of the sea and of icebergs on the forms of rocks.—168. Geological phenomena explicable by natural causes still in operation.—169. Portland dirt-bed—Its organic deposits.—170. Climate of England tropical at the epoch of these deposits.—171. Example of coal deposits.—172. Northumberland coal mines.—173. Colliery near Wolverhampton.—174. Deposits in Treuille mine at St. Etienne.—175. The character of the waters shown by the organic deposits—Fossil shells.

153. It has been impossible to obtain direct observations of the interior of craters when in a state of active eruption, but when they have been approached immediately after the cessation of an

eruption, these cavities appear to have generally a conical form, the base of the cone being presented upwards, and the lower part filled with consolidated lava, by which the principal chimney of the crater is covered. Sulphurous vapour is observed to issue from its fissures and interstices, sometimes several open gulfs are seen, from some of which vapours are emitted, and at the bottom of others incandescent lava is seen. Others again are silent and dark, and inspire an indescribable sense of terror.

154. The crater Stromboli, which has been in activity since the most ancient times, presents at present the same appearances as those which were described by Spallanzani, in 1788. It is constantly filled with lava in a state of fusion, which alternately rises and falls in the cavity. Having ascended to ten or twelve yards below the summit of the walls, this boiling fluid is covered

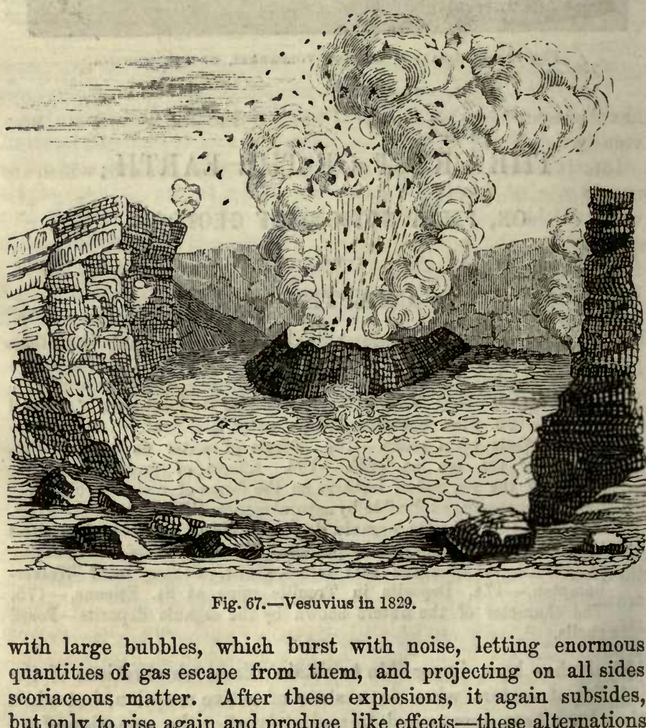


Fig. 67.—Vesuvius in 1829.

with large bubbles, which burst with noise, letting enormous quantities of gas escape from them, and projecting on all sides scoriaceous matter. After these explosions, it again subsides, but only to rise again and produce like effects—these alternations being repeated regularly at intervals of some minutes. In craters

where the lava is less fluid than in that of Stromboli, new cones are sometimes formed in the midst of the crater, which first rise in the form of a dome, and then burst out so as to form a small active volcano in the middle of the crater of the great one. This phenomenon is often presented within the crater of Vesuvius (fig. 67) and was more particularly witnessed in 1829.

155. Sometimes the lava, which is pressed upwards instead of being violently ejected, spreads itself in a sheet of greater or less thickness over the surface (fig. 68) where it hardens, and is subsequently covered by other deposits. Cases have been found also where a succession of these strata, formed at different intervals, with interposed strata of other matter, have been observed (fig. 69). In such cases the matter forming the superior stratum is seen to

Fig. 68.

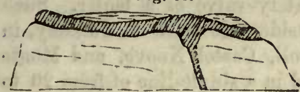
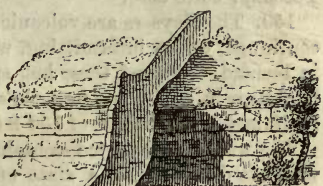


Fig. 69.

have passed in a liquid state through the inferior strata previously described.

156. It often happens that the lava is solidified in clefts, which are nearly vertical, and thus forms walls, called *dykes*, which frequently rise to the surface. In such cases the solidified lava, being much harder and less susceptible of degradation from atmospheric and aqueous influences, remains standing when the matter surrounding it is swept away, and thus forms a wall rising above the general surface (fig. 70).

Fig. 70.



157. The phenomena of Salses, or mud volcanoes, has been already briefly noticed in our Tract upon "Earthquakes and Volcanoes," Vol. IV. p. 169. The mud volcanoes are characterised also by the conical form, but their cones are much less elevated, their slopes being flatter (fig. 72). They have at their summit a crater-formed cavity frequently filled with liquid mud, on which large bubbles are continually formed which, bursting, scatter around them earthy matter. There are sometimes, over a surface of little extent, a great number of these cones in full activity, some of which have a height of ten or twelve yards. Sometimes such an assemblage of cones is found at the summit of a mound from fifty to two hundred yards in height, formed of argillaceous

matter, which appears to have been the result of former ejections. The middle is often formed of a lake of mud, the surface of which is more or less consolidated. In certain countries these mounds are found permanently dried, all disengagement of gas, water, and earth having altogether ceased, but it sometimes happens that the same phenomena after long cessation are renewed with violence.

158. Fumarolles and Geysers are the names given to eruptions of steam or boiling water issuing from crevices in volcanic districts, remarkable examples of which are presented in the country surrounding the celebrated volcano of Hecla, in Iceland. Eruptions of hot steam are projected from the crevices of the soil in the form of white columns, rising to heights of from 30 to 60 feet, and often with noise similar to that with which high pressure steam issues from the safety-valve of a boiler. Such phenomena are manifested on a considerable scale in Tuscany, in the neighbourhood of Monte Cerboli, Castel Nuovo, and Monte Rotondo, and are generally disposed in a single line of from 20 to 25 miles in length.

These jets of vapour in all cases include chemical agents, which attack the rocks with which they come in contact; thus the vapour ejected from Vesuvius includes hydrochloric acid, that of the Solfatara, of Pozzuoli, includes sulphurous acid, and that of Tuscany, boric acid.

159. The Geysers are volcanic eruptions of boiling water, some continued, others intermitting, which prevail in immense numbers in Iceland. One of these hot springs is mentioned which, from half-hour to half-hour, projects a column of boiling water 18 feet in diameter to a height of 150 feet (fig. 71).

The water thus ejected contains a certain proportion of silica, which is deposited in a state of hydrate upon all the surrounding bodies, and forms sometimes mounds of considerable extent, at the summit of which is an opening, from which the liquid issues.

Besides silica, the water of the geysers also contains, in a small proportion, the carbonates or sulphates of soda, ammonia, potash, and magnesia, besides a minute proportion of carbonic acid.

160. Calcareous as well as volcanic countries present vast depressions of the ground analogous to craters, but instead of being nearly circular like those of volcanoes, they are most frequently oblong and very irregular. Such cavities are frequent in the mountains of the Jura. These are generally oblong hollows, like clefts, which sometimes extend to a great distance, forming oblong mounds parallel to each other, with salient summits. These depressions or cavities (fig. 73) have received the name of

valleys of elevation, though they differ in nothing except their form from craters of elevation.

Fig. 73.

161. Elevations of the superficial crust often take place in a series of parallel lines forming so many parallel ridges with intermediate hollows, as if an upheaving force had been exerted by the subjacent strata in a series of parallel directions vertically under the ridges thus produced. The Jura mountains present great numbers of examples of this (fig. 74).

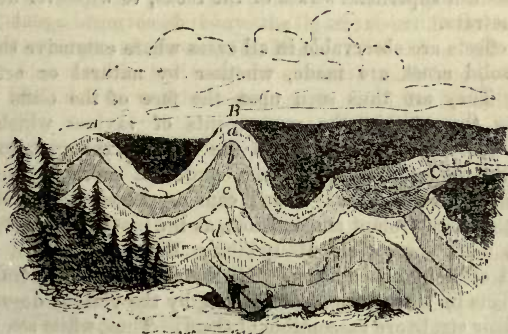


Fig. 74.—Section ot ridges in the Jura Mountains.

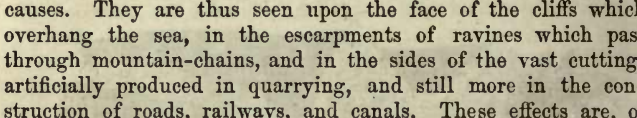
162. The changes in the condition of the earth's surface attending the undulations and disruptions of its crust, which have been noticed above, excite attention because of the sudden catastrophes which often attend them, and the wide devastation which they sometimes spread. There are, however, other agencies exterior to the surface, of which the accumulated effects, produced in long intervals of time, are not less important. The principal of these are air, water, and heat, acting separately or together, upon the solid matter of the external surface of the terrestrial crust. These operate mechanically by fracture and abrasion, physically by dissolution and disintegration, and chemically by decomposition.

The waters of the ocean evaporated by heat rise into the superior parts of the atmosphere, and are carried by atmospheric currents in their course towards the most elevated parts of the land, where they are condensed, and upon which they are precipitated in the liquid state; thence they descend along the declivities, forming rivers and lakes, and sometimes penetrating the crust so as to form springs, until at length, sweeping over the land, they return to the deep, carrying with them, however, a large quantity of detritus of the solid crust, over which they have passed, and which they deposit in the bottom of the sea to form new systems of strata.

Independently of water, air itself by its mechanical action upon solid matter detaches, fractures and abrades more or less of it. The water suspended in the form of vapour in the atmosphere penetrates the pores and interstices of rocks to a greater or lesser extent, according to their density and structure. In times of drought it is again expelled by evaporation, and being thus alternately and incessantly absorbed and dismissed, it at length disintegrates the superficial strata of the rocks, to whatever depth it may penetrate.

Such effects are observable in all cases where extensive sections of the solid crust are made, whether by natural or artificial causes. They are thus seen upon the face of the cliffs which overhang the sea, in the escarpments of ravines which pass through mountain-chains, and in the sides of the vast cuttings artificially produced in quarrying, and still more in the construction of roads, railways, and canals. These effects are, of course, the more prompt and sensible, as the matter composing the rocks is more susceptible of imbibing humidity and of being deprived of it by evaporation. All mountains exhibit traces of such effects in some forms, determined by the various degrees in which their strata are susceptible of them. Thus, while some, like volcanic cones, assume uniform slopes in a conical form, fig. 75 A; others, those composed of gneiss, for example, assume the forms of pointed and dentated peaks, fig. 75 B. Numerous examples of

Fig. 75.



A B C D

these are seen in the chains of the Alps, where they take the names of *needles*, *teeth*, and *horns*, (aiguilles, dents, and cornes,).

according to their varying forms. Calcareous cliffs assume cylindrical forms, fig. 75 C, which seem at a distance to resemble fortifications. The faces of these cliffs are often worn into a succession of terraces or steps, as in fig. 75 D.

163. The effects of long-continued atmospheric action upon the forms of solid rocks, are seen in many places on the surface of continents, which the sea has not approached within historic times. Certain granites are thus disintegrated so profoundly, as to reduce the under-surface of the strata to a mass of gravel, forming holes into which the pluvial water from ravines flows in all directions. These rocks are also sometimes met with worn into rounded forms, and piled one upon another, so as to be supported only at a single point, forming what are popularly called *rocking-stones*, fig. 76 B. Cases of this kind are especially presented in the case of certain porphyritic granites. In mountains where granite is decomposed with facility, it has been remarked that masses of these rocks, more or less divided, present a sort of horizontal layers, separated by vertical fissures, so as to reduce the whole to a pile of irregular parallelopipeds, fig. 76, C. The angles and edges being often worn away, the mass is reduced to a form resembling a pile of cheeses, fig. 76 A.

Fig. 76.

A B C

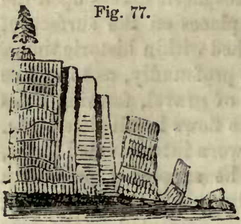
164. Solid rocks are often traversed by vertical crevices filled with matter more easily penetrable by water. In such cases, the pluvial waters entering these crevices dissolve and ultimately sweep away the matter which fills them, leaving the parts thus separated without support. These ultimately fall to the foot of the cliff (fig. 77).

165. When waters bathe the foot of steep cliffs, they have a tendency to dissolve and decompose their lower strata, leaving

the superior ones undisturbed and, consequently, overhanging. When this action is continued to a certain point, the cliffs thus overhanging fall by their weight (fig. 78).

It sometimes happens that the accumulation of the débris of such cliffs which takes place below them, operates as a barrier to the waves, and so, for a time, protects them from further degradation (fig. 79). In some cases the natural form of the rocks exposed to the action of the waves enables them to resist these effects, and such forms are accordingly often imitated in the construction of harbours and breakwaters (fig. 80).

Fig. 77.



166. Cascades have often the same effect in the degradation of the cliffs over which they fall, as have the action of waves directed against their base. When such cliffs are formed of

Fig. 78.

alternate calcareous and argillaceous matter, the former, being more susceptible of disintegration than the latter, absorbs and is

Fig. 79.

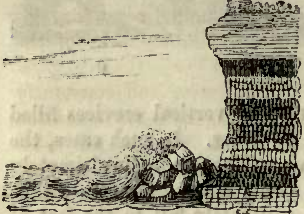


Fig. 80.

worn away by the water either in its fall, or by its recoil from the foot of the cascade; the cliff, therefore, over which the torrent falls soon overhangs (fig. 81) and at length is broken off by its weight.

167. It is to the operation of such causes, as well as to the action of icebergs floating from the Pole, that various forms of rocks found in the ocean, but more especially in the neighbourhood of continents, must be ascribed. The action of the sea disintegrates the softer parts, leaving the harder standing, and thus forms the most capricious are produced. Wide clefts and openings are made between solid rocks through which the sea passes, and in some cases the rocks are broken into rude and irregular columns and needles (figs. 82 and 83.)

Fig. 81.

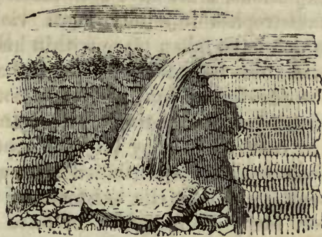


Fig. 82.

Fig. 83.

Other similar examples are presented in the case of the chalk-cliffs near the French village of Etretat on the Channel coast (fig. 84) and also in the porphyritic and granitic columnar rocks of the Shetland Isles (fig. 85).

168. Thus, in fine, it appears that there are, and constantly have been, within historic times, natural agencies in operation upon the surface of the globe, sufficient to explain all those phenomena observed by modern geologists, which, when first brought under notice, excited sentiments of such unmixed wonder. Alternate elevations and depressions of the earth's crust, either sudden or gradual, are recorded in all times; and it is easy to imagine that, in proportion as the shell of solid matter which incloses the igneous central fluid was less and less thick, and

consequently less and less resisting, so at more and more remote periods, these undulations, and their consequent disruptions and explosions, must have been much more frequent, and attended by catastrophes infinitely more violent. The volcanic eruptions which have taken place within historic times, may be regarded as miniature reproductions of the phenomena of which the globe was the theatre at much more remote geological dates. The wear, abrasion, decomposition, and transport of the solid materials of the earth's crust by the action of atmosphere and the waters of the ocean, when continued through periods compared with which that limited by the existence of the human race is but a unit, can easily be imagined to have produced all the effects which are visible on the earth's surface, and to greater or less depths within its crust. The deposits formed by the detritus of the land

Fig. 84.

Fig. 85.

carried by the currents of rivers to their embouchures, exhibit on a small scale the stratification produced by pre-Adamite seas. In a word, all the geological phenomena discoverable by the sections, natural or artificial, of the earth's crust, admit of clear and satisfactory explanation, by merely imputing to the physical agents now in operation an energy proportional to the diminished thickness of the earth's crust, and effects due to a continuance of action for periods of time, compared with which the common chronological units must be regarded as insignificantly minute.

Having thus briefly indicated the natural causes to which geological phenomena must be ascribed, we shall resume the subject which we had dropped, and continue our notice of some of these results, which illustrate the past condition of the earth.

169. There exists in England, in the Isle of Portland, as well as elsewhere, and on various parts of the continent, a stratum called by miners and quarrymen the "*dirt-bed*." This consists of

a layer about one foot in thickness, composed of dark brown friable loam, containing a large proportion of earthy lignite, and, like the recent soil of the island, many water-worn stones and pebbles. It seems to have been a bed of vegetable mould, which at a remote geological epoch supported an abundant and luxuriant vegetation, for we find in it and upon it innumerable trunks and branches of cone-bearing trees and cycadeous * plants. Above this bed are found layers of finely-laminated cream-coloured limestones, the total thickness of which is about ten feet, and upon which is deposited the modern vegetable soil; but this latter at present, instead of supporting cycadeous plants and pine forests, barely maintains a scanty vegetation.

The most remarkable circumstance attending this dirt-bed, as it is called, is the position of the trees and plants found on it. They are still erect, as though they had been suddenly petrified while growing in their native forests, with their roots in the vegetable soil and their trunks extending into the limestone above it.

Immediately below it is a thick stratum of fresh-water limestone, of little value for building; and below this again is the stratum of the celebrated Portland stone so extensively used for that purpose. The consequence is that the dirt-bed and its interesting materials, little regarded by quarrymen, are cast away and scattered about as mere rubbish, in order to get at the layer of building-stone which lies below them. "On one of my visits to the island (in the summer of 1832)," says Dr. Mantell, "the surface of a large area of the dirt-bed was cleared, preparatory to its removal, and the appearance presented was most striking. The floor of the quarry was literally strewn with fossil wood, and before me was a petrified forest, the trees and plants, like the inhabitants of the city in Arabian story, being converted into stone, yet remaining in the places which they occupied when alive! Some of the trunks were surrounded by a conical mound of calcareous earth, which had evidently, when in a state of mud, accumulated round the stems and roots. The upright trunks were generally a few feet apart, and but three or four feet high; their summits were broken and splintered, as if they had been snapped or wrenched off by a hurricane, at a short distance from the ground. Some were two feet in diameter, and the united fragments of one of the prostrate trunks indicated a total length of from thirty to forty feet; in many specimens portions of the branches remained attached to the stems. In the dirt-bed, there were numerous trunks lying prostrate, and fragments of branches.

"The external surface of all the trees I examined was weather-

* Such as palms and ferns.

worn, and resembled that of posts and timbers of groins or piers within reach of the tides, and subjected to the alternate influence of the water and atmosphere; there are but seldom any vestiges of the bark.

"The fossil plants related to the recent Cycas and Zamia,* occur in the intervals between the pine-trees; and the dirt-bed is so little consolidated, that I dug up with a spade, as from a parterre, several specimens that were standing on the very spot where they originally grew, having, like the columns of the temple of Pozzuoli, preserved their original erect position amidst all the revolutions which have subsequently swept over the surface of the earth, and buried them beneath the accumulated detritus of innumerable ages. These fossil plants, though related to the recent Cycadeæ, belong to a distinct genus.† There are two species—one is short, and of a spheroidal form (M. nidiformis); the other is longer, and subcylindrical (M. cylindrica). ‡

"The trees and plants are completely silicified, and their internal structure is beautifully preserved in many examples; the wood, microscopically examined, displays the organisation of the Araucaria. A cone has been found in the dirt-bed, which Dr. Brown considers to be nearly related to the fruit of the Norfolk Island pine (Araucaria excelsa). The Portland and Isle of Wight fossil trees appear to belong to the same species of Coniferæ." §

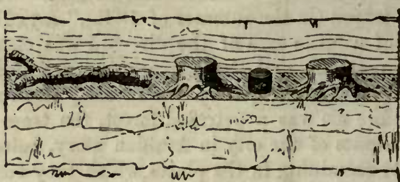


Fig. 86.—Section of the Portland dirt-bed.

170. The presence of plants analogous to the modern Cycas and Zamia shows that the climate of England, at the time when the vegetation of this stratum flourished, must have been

* These plants are so common in conservatories that their general appearance must be familiar to the reader. In the Botanic Gardens at Kew there are magnificent specimens of Cycas and Zamia, and of other plants of hot climates, of which related forms occur in the Wealden.

† Named by M. Adolphe Brongniart, *Mantellia.*

‡ Specimens of the former species are called "*crows'-nests*" by the quarrymen, who believe them to be birds' nests originally built by crows in the pine-trees, and which have since become petrified.

§ Mantell, p. 387.

analogous to that of the tropics, a fact which is in conformity with what has already been explained.

171. The coal deposits are everywhere attended with similar results. Entire trees are found, some of which are standing upright with their roots penetrating the stratum below them, exactly as they penetrated the soil on which they grew. Several examples of these have been presented in England, one of the most remarkable of which occurred in the construction of the railway between Manchester and Bolton. Near Dixonfold five large stems of Sigillariæ were found erect with their roots striking into layers of clay below. They stood upon the same level one beside the other, the trunks being surrounded and filled by soft blue shale, and the carbonised bark being all that remained of the original structure. All these trunks seemed to have been broken violently off at a point four or five feet above the roots, no traces of the upper parts of the trees being discovered.

172. On the coast of Northumberland, within a space of half a

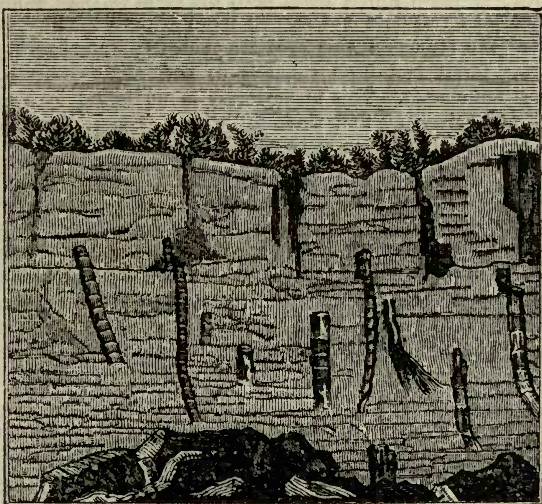


Fig. 87.—Section of the Treuille Mine at St. Etienne.

mile in length, twenty upright trees were discovered by Mr. Trevelyan, and similar ones were found in the same coal-field at some distance, as if they had been the continuation of a submerged forest like that of the Isle of Portland.

In the Newcastle coal-field a stratum of sandstone occurs

nearly five hundred feet below the surface, on which numerous trees have been found standing erect from two to eight feet in circumference, with their roots struck into thin layers of coal.

173. "In a colliery near Wolverhampton," says Hugh Miller, "the bottom coal rises to view, and where the surface has been cleared of the alluvial covering, it presents the appearance of a moor on which a full-grown fir-wood had been cut down a few months before, and only left the stumps behind. Stump rises beside stump, to the number of seventy-three in all: the thickly clinging roots strike out on every side into what seems once to have been vegetable mould, but now exists as an indurated brownish-coloured shale. Many trunks, sorely flattened, lie recumbent on the coal; several are full thirty feet in length, while some of the larger stumps measure rather more than two feet in diameter. There lie, thick around, Stigmariæ, Lepidodendra, Calamites, and fragments of Ulodendra; and yet with all the assistance which these lent, the seam of coal formed by this ancient forest does not exceed five inches in thickness. Not a few of the stumps in this area are evidently water-worn. The prostrate forest had been submerged, and molluscs lived, and fishes swam over it. This upper forest is underlaid by a second, and even a third: we find three full-grown forests closely packed up in a depth of not more than twelve feet." *

174. M. Alexandre Brongniart † describes a coal-pit at Treuille near St. Etienne, in the neighbourhood of Lyons, which contains enormous stems of Calamites and other trees in erect positions (fig. 87). These and similar effects are considered as proofs that the coal was produced by the submergence of a forest which grew upon the spot. This particular mine is very favourable for observations being in the open air, and presenting a natural succession of the strata of clay, slate, and coal, with four layers of compact iron-ore in flattened nodules, accompanied and even penetrated by vegetable remains.

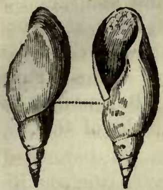
The upper ten feet of the quarry consist of micaceous sandstone, which is in some instances stratified, and in others has a slaty structure. In this bed are enormous vertical stems traversing all the strata, and appearing like a forest of plants resembling the bamboo or large *Equiseta* petrified on the spot on which they grew. The stems are of two kinds, one long and thin, from one to four inches in diameter, and nine or ten feet high,

* First Impressions of England and its People, by Hugh Miller, p. 223.

† Notice sur les Vegetaux fossils traversants les Couches du Terrain houilleux, par M. A. Brongniart, Paris, 1821.

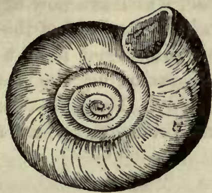
consisting of jointed and striated cylinders with a thin coaly bark. The other and less common species consist of hollow cylindrical stems spreading out from the base like a root.

Fig. 88. Fig. 89.



Limnea longiscata.

Fig. 90.



Planorbis evonphalus.

Fig. 91.

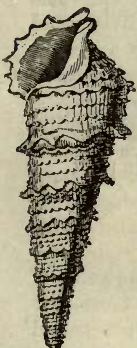
Paludina lenta.

Fig. 92.

Melania.

175. The character of the waters, according as they may have been fluviatile and lacustrine or marine, from which the several strata forming the crust of the earth were deposited, is betrayed by the nature of the organic remains which these strata severally contain. Thus, if we find shells (figs. 88 to 92) analogous in their character to existing fresh-water shells, it may be inferred that the deposits were fluviatile and lacustrine, or at all events that they were fresh-water deposits.

Fig. 93.



Cerithium mutabile.

Fig. 94.

Murex alveolatus.

Fig. 95.

Voluta athleta.

Fig. 96.

Venericardia imbricata.

If, on the other hand, none but marine shells (figs. 93 to 96) be found in any stratum, it may be inferred that such stratum was submerged by the ocean from which the deposits were made.

In cases where the organic remains are of a mixed character, containing shells and other fossils, some analogous to existing marine and other species, it may be inferred that such deposits were made at the embouchures of rivers.

By such inductions it has been ascertained that extensive tracts of the surface of the globe, which are now dry land and raised to elevations considerably above the level of the sea, must, at various former epochs, have been submerged in the waters of the ocean. A great part of France, including the country around Paris, Normandy, Artois, Picardy, Franche-Comté, Burgundy, the Cevennes, Dauphiny, and Provence, present examples of this.

Fig. 108.—Fossil footprints in the strata of the new red sandstone.

THE CRUST OF THE EARTH;

OR, FIRST NOTIONS OF GEOLOGY.

CHAPTER VII.

176. Fossil foraminifera—177. Fossil infusoria—Researches of Ehrenberg. —178. Marine deposits at great heights, produced by former undulations of the land.—179. Organic deposits show that the same parts of the land have undergone a series of alternate elevations and depressions.—180. Example of the Portland beds.—181. Fossil footsteps.—182. Such traces common in the new red sandstone, at Hesseburg, and near Liverpool.—183. Footprints of birds.—184. Fossil rain-drops and ripple-marks.—185. Conclusion.

176. Besides the larger class of fossil shells, there are numerous infinitely more minute ones, which have largely contributed to the formation of the actual crust of the globe, the principal of which are the Foraminifera and Infusoria.

The Foraminifera are marine animals of low organisation, and generally of such extreme minuteness, that an ounce of sea-sand will contain three or four millions of them. The body consists of uniform granules enclosed in a skin or membrane

Fig. 97.

Nautilus truncatus.

Fig 98.

Ammonites catena.

Fig. 99.

Serpula.

having one or more cavities or digestive sacs. These animals are regarded as *polypes*, and are protected by shells. Some of these shells, such as the Orbiculina, contain a single cell. Others, such as the Nodosaria, consist of several cells disposed in conical or cylindrical directions. Other families have shells, like that of the Nautilus, consisting of a succession of cells in spiral forms.

The Foraminifera derive their name from the structure of the shell, which consists of one or more series of chambers separated from one another by septa or partitions, in each of which there is a small perforation called a foramen.

Some specimens of these shells, on a highly magnified scale, are given in figs. 100 to 106.

These microscopic shells, of which from seven to eight hundred fossil species have been discovered, are accumulated in enormous numbers in the strata of the earth, and, in many cases, exclusively form very considerable calcareous deposits, of which the chalk and the cretaceous and tertiary strata present numerous examples in all parts of the world.

177. The Infusoria, the existing species of which are found in

fresh and salt water, are smaller still than the Foraminifera, being only visible by the aid of microscopes of great magnifying power. There are innumerable species of them, which are furnished with siliceous shells, and which, consequently, are accumulated at the bottom of the waters with the contemporaneous microscopic plants. Now, although these beings are so minute that forty thousand millions of them would not fill a space of

Fig. 100.

a b

Fig. 101.

a b c

Fig. 102.

a b

Fig. 103.

a b

Fig. 100.—*a*. Nodosaria limbata.
b. Internal arrangement of the cells.
,, 101.—*a*. Marginulina trilobata.
b. The last cell seen from above.
c. The internal arrangement of the cells.

Fig. 102.—*a*. Flabellaria rugosa.
b. Side view, to show the flatness.
,, 103.—*a*. Textularia turris.
b. Internal arrangement of the alternate cells.

more than a cubic inch, M. Ehrenberg has demonstrated that their accumulation in certain parts of the earth's crust has pro-

Fig. 104.

Fig. 105.

a b

Fig. 106.

Fig. 104.—Rotulina Voltzii.
,, 105.—*a*. Cristellaria rotula.

Fig. 105.—*b*. Edge view, to show the flatness.
,, 106.—Orbiculina numismalis.

duced strata several yards in thickness, and of vast extent; and that in many other cases strata not less extensive are formed by their combination with other conchiferous animalcules. They constitute almost exclusively the polishing slate of Bilin, in Bohemia, which occupies a surface of great extent, probably the site of an ancient lake, and forms a stratum fourteen feet in thickness, composed of the mineralised shields of these animalcules. "The diameter of a single one of these creatures," says M. Ehrenberg, "amounts upon an average, and in the greatest part, to the 3500th of an inch, which equals $\frac{1}{6}$ of the thickness of a human hair, reckoning its average size at the 570th of an inch. The globule of the human blood, considered at the 3600th of an inch, is not much smaller. The blood globules

of a frog are twice as large as one of these animalcules. As the Polirschiefer of Bilin is slaty, but without cavities, these animalcules lie closely compressed. In round numbers, about twenty-four millions would make up a cubic line, and would, in fact, be contained in it. There are 1728 cubic lines in a cubic inch; and therefore a cubic inch would contain, on an average, about forty-one thousand millions of these animals. On weighing a cubic inch of this mass, I found it to be about 220 grains. Of the forty-one thousand millions of animals, a hundred and eighty-seven millions go to a grain; or the siliceous shield of each animalcule weighs about $\frac{1}{187}$ millionth part of a grain."

The remains of these Infusoria are often found in abundance in flints, opals, and more especially in the earthy matter which envelopes the translucent parts. They exist in large quantities, also in most marls, especially in those of lacustrine depositions in calcareous slates of the same formation, and in all chalk strata. They form the chief part of the deposits which fill the gulfs and arms of the ocean, and are found in all the earthy deposits raised from the bottom of the waters in ancient and modern times. They exist in strata sixty feet thick in the low plains of Western Germany, at a depth greater or less under the sands of those countries. It is a remarkable fact, that one of the strata on which the city of Berlin is placed, is formed of the shells of Infusoria which still live and are propagated and sustained, doubtless, by the waters of the Spree, on which that city is built.

M. Ehrenberg has described numerous fossil genera and species of Infusoria found in all parts of the world, and in different strata, a few of which are represented on a high magnified scale in fig. 107.

178. At whatever heights upon the land fresh-water shells and the remains of land animals may be found in the sedimentary strata, no surprise can be excited, since it is perfectly conceivable that at various epochs any portions of the land, whatever be its level, may have been submerged by lakes or overflown by rivers. But we find, also, at all levels, no matter how high, even at the summits of lofty ranges of mountains, marine deposits in strata of immense extent and vast thickness.

179. In many places an analysis of the strata shows the most curious alternations between fresh-water and marine deposits, which can only be explained by the supposition that the crust of the globe at these places has undergone a succession of elevations and depressions, and that after being submerged for an indefinite period, and receiving marine deposits, it was then upheaved so as to become dry land; and that during another indefinite period it was peopled by land and fresh-water animals, and covered with a

certain vegetation: that then it was again submerged, either by fresh water or by the sea, receiving during an indefinite period another stratum, either with fluvial and lacustrine remains or with marine deposits, as the case might be; that subsequently it was again upheaved, and again became the theatre of animal and vegetable life upon dry land, and so on.

180. The Portland dirt-beds, already described, prove the existence there, at remote epochs of the globe, of vegetable soil on a land nearly if not altogether dry, beneath which lay a stratum of marine deposits. It follows, therefore, that before this epoch, and before the deposition of the dirt-bed itself with the remains contained on it, that part of the land must have been submerged by the ocean, and that being upheaved, it afterwards became the theatre of animal and vegetable life, such as we find deposited in

Fig. 107.—Fossil infusoria.

a. Desmidium apiculosum.
b. Euastrum verrucosum.
c. Xanthidium ramosum.
d. Peridinium pyrophorum.
e. Gomphonema lanceolata.
f. Hemanthidium arcus.
g. Pinnularia dactylus.
h. Navicula viridis.
i. Actinocyclus senarius.
j. Pixidula prisca.
k. Gallionella distans.
l. Synedra ulna.
m. Bacillaria vulgaris.
n. Spicula spongiaria.

the dirt-beds. Over the dirt-beds are thick lacustrine deposits of limestone, which lie under the green sandstone, which latter is itself overlaid by the chalk, this latter being evidently a marine formation. Let us see, then, what a curious succession of phenomena is here indicated. The lower marine strata of limestone was first upheaved, and, becoming dry land, was the theatre of rich terrestrial vegetation. It was then submerged by fresh water, and was the place of a lake or deep estuary, in which were formed the strata of limestone, sand, and clay, filled with fluviatile shells, forming a stratum, which from actual observation appears to have a thickness of from seven hundred to a thousand feet. Later still, this was covered by the sea, and marine deposits of green sandstone and chalk were formed upon it, which, at

certain places, had a still greater thickness. In fine, at a later period still, another great elevation of the crust took place, which raised the surface to its present elevation above the waters.

181. Independently of the evidence supplied by organic remains proving that certain strata were at former epochs above the waters and inhabited by land animals, and were subsequently submerged, indications of another order have been supplied by the traces left by animals in the soft surface of the strata, which were afterwards hardened without these traces being effaced. Such traces, therefore, may be regarded as moulds thus accidentally preserved, from which castings might be obtained of those parts of the animals, then living upon the globe, which produced them. Many moulds of shells have been thus found, but the most remarkable indications of this kind consist of the footsteps of certain animals which appear to have been impressed upon the soft surface of the ground, just as the footsteps of any animals might be at present impressed upon the soft sand upon the sea-shore after the retirement of the tide.

182. In 1834 an account was published of remarkable fossil footprints in the new red sandstone at Hesseburg, near Hildburghausen, in Saxony. The largest of these tracks appears to have been made by an animal whose hind-foot was eight inches long, and which, from its resemblance to the human hand, received from Professor Kaup the name of Chirotherium. Some of the tracks, however, appeared to be those of tortoises; and Link suggests that others are those of some colossal species of frog or salamander, fig. 109.

Fig. 109.—Labyrinthodon pachignatus (Owen).

The traces represented in fig. 108 are those found in a sandstone slab at Hesseburg. Various similar tracks have been found in the sandstone quarries at Storeton Hill, near Liverpool. The largest footprint was nine inches long and six inches broad, the length of the step being nearly two feet. Similar tracks were found by Professor Hitchcock in the quarries of Connecticut; and Mr. Scrope found similar marks on a surface bearing ripple-marks in the vast marble-quarries near Bath.

These last are supposed to have been made by some crustaceous animal crawling along the bottom of an estuary; for between the rows of footprints are in some cases observed the impressions of the belly, and in others the trail of the tail.

183. Footprints of birds have been discovered in several quarries in the valley of the Connecticut river, and also in different parts of the state of Massachusetts. Several specimens of these are now in the British Museum. The most remarkable of these is a slab, eight feet by six, exhibiting various tracks of birds, (fig. 110).

Fig. 110.—Fossil footsteps of birds.

All these marks belong to the birds called *waders*, and appear to have been made upon the sea-shore. Some are small, others of a size so enormous that they could only have belonged to birds twice the size of the largest ostrich. In one case the footprint measures fifteen inches in length by ten in width, without counting the hind-claw, which itself measures two inches. The distance

between the successive footprints varies from four to six feet. The shorter footsteps may be taken as the length of the step when the bird walked at its ordinary pace, and the larger one when it moved more swiftly.

184. A very remarkable concomitant of some of these fossil footprints is the distinct impressions of rain-drops upon the strata. Dr. Dean discovered a stratum containing more than a hundred marks of the feet of birds of various species, the whole surface of which was pitted by the marks produced by a heavy shower of rain. Like marks were observed in Storeton quarry, near Liverpool. The impressions produced by the rain-drops were sometimes perfect hemispheres, an indication of a heavy fall of rain in a vertical direction, and consequently in a calm atmosphere. In other cases the impressions were irregular and oblong, as if the drops had struck the surface obliquely, as when a shower is accompanied by a strong wind.

Professor Hitchcock also mentions specimens of sandstone obtained from various parts of the United States, showing at once footprints, ripple-marks, and rain-drops, the latter being elongated by the direction of the wind when the shower was falling.

These phenomena can only be explained by the fact that the marks were made upon the moist sand formed on the shores of an estuary or tidal river, between high and low water mark, which then was allowed to dry and harden by the action of the sun and air between two successive tides. The waters on the return of the tide would wash up silt to cover up the impressions without impairing their accuracy; the two layers uniting so as to exhibit when separated the one a shield, and the other a cast from it of the form thus impressed.

185. Our necessary limits, rather than the exhaustion of the subject, compel us here to close these first glimpses of geology. We propose, however, in a succeeding paper, to resume the subject, and to give a brief sketch of the History of the Earth from the first formation of its solid crust to the last great act of creation which called the human race and its concomitant tribes into existence.

Fig. 1.—Cuvier.

Fig. 2.—Cuvier.

THE STEREOSCOPE.

1. Surprising effect of the instrument explained.—2. Causes of visual perspective and relief.—3. Effects of binocular parallax.—4. Example of the bust of Cuvier.—5. Principle of the stereoscope.—6. Origin of the name.—7. Wheatstone's reflecting stereoscope.—8. Sir David Brewster's lenticular stereoscope.—9. Method of obtaining stereoscopic pictures.—10. How the effects of relief are produced.—11. Natural relief greatly exaggerated.

1. The surprise excited by the impressions of perspective and relief produced by the stereoscope have never, as we think, been fully or adequately explained. This emotion of astonishment does not merely arise, as is commonly supposed, from the fact that such impressions are stronger than those produced by the best executed drawings or paintings, but that, paradoxical as it may seem, they are actually in many cases stronger and more vivid, than any which could be produced by the objects themselves. In a word, the stereoscope has the property of exaggerating the natural effects of perspective and relief. To comprehend this it will only be necessary to revert for a moment to the principles upon which the effects of vision are based.

The mind judges of the relative position, form, and magnitude of visible objects, by comparing their apparent outlines and varieties of light and shade, with previously acquired impressions of the sense of touch. The knowledge that such and such visual appearances and optical effects are produced by certain varieties of form, position, and distance having been already acquired, it substitutes with the quickness of thought the cause for the effect. The continual repetition of such acts, which are necessarily repeated as often as the sense of vision is exercised, and the extreme rapidity with which all such mental operations are performed,

render us unconscious of them, and we imagine that shape, distance, and position are the immediate subjects of visual perception, instead of being consequences deduced from a set of perceptions of a wholly different kind.

2. In drawing and painting, the effects of perspective and relief are therefore reproduced, by transferring to the canvas the same outlines and the same varieties of light and shade, which the objects delineated really present to the eye, and when this has been accomplished with the necessary degree of fidelity and precision, the same impression of distance, perspective, and relief is produced, as that which would be received from the immediate view of the objects themselves which are delineated.

3. In certain exceptional cases, however, a class of visual phenomena is manifested which are quite independent of mere outline and varieties of light and shadow, and which no effort of art can transfer to canvas. Inasmuch, also, as these phenomena, like those already mentioned, are optical effects of distance, form, and position, they become, like the others, indications by which the mind judges of the relative forms and positions of the objects which produce them. Phenomena of this class are manifested, when the objects viewed are placed so near the observer, as to have sensible binocular parallax. The aspects under which they are seen in this case by the two eyes, right and left, are different. Certain parts are visible to each eye which are invisible to the other, and the relative positions in which some parts are seen by one eye, differ from those in which the same parts are seen by the other eye. This difference of aspect and apparent position, arises altogether from the different position of the two eyes in relation to the objects. It is a phenomenon, therefore, which can never be developed, in the case of objects whose distance bears a large proportion to the distance between the eyes, because there is no sensible difference between the aspects under which such objects are viewed by the one eye and the other. The phenomenon, therefore, can only be manifested in relation to objects, whose distance from the observer is a small multiple of the distance between the eyes.

4. To render this more clear, let us imagine a bust presented to an observer at a distance of a few feet, the face being turned obliquely so that one side is presented more to view than the other. Supposing the side which is turned towards the observer to be on his right, it is evident that the nose will intercept, more or less, the view of the side of the face which is on his left, but the part which it thus intercepts will not be the same for both eyes. It will evidently intercept more from the right than the left eye. On the other hand, the right eye will see a part of the

right side of the bust, which will be concealed from the left eye by the projecting parts of the face.

It therefore appears that the two eyes, right and left, will have different views of the bust; so that if the observer were to make an exact drawing of the bust with his left eye closed, and another exact drawing of it with his right eye closed, these drawings would not be identical. One of them would show a part of the bust on the extreme right, which would not be exhibited in the other, and the latter would show a part on the extreme left, which would not be included in the former. Moreover, a part of the cheek and the eye would be shown in the drawing made with the right eye closed, which would not appear in the drawing made with the left eye closed.

Two such views of the same object are shown in figs. 1 and 2, the former being the view presented to the left and the latter to the right eye.

Now it is evident that when such an object is looked at with both eyes open, the two different visual impressions here described are simultaneously perceived, and they become to the mind signs and indications of the actual forms which produce them.

When objects, therefore, can be viewed at distances small enough to be attended with a sensible degree of parallax, their perspective and relief are perceived, not only by the outlines and varieties of light and shade, which are the common indications of perspective and relief at all distances, but also by the class of binocular phenomena which we have just described.

Hence it follows that the perception of relief, and generally of form and relative position in objects whose proximity is sufficient to produce binocular parallax, is much stronger and more vivid than those whose distances, rendering the binocular parallax evanescent, leaves nothing but the outlines and the varieties of light and shadow, by which the mind can form a judgment of form, relative distance, and position.

But since binocular parallax is reduced to the very small amount of half a degree at the distance of 24 feet, it is clear that it can only enter into the conditions by which we perceive perspective and relief, in the case of a very limited class of objects, and is not at all applicable to objects in general whose forms and perspective we habitually contemplate.

5. After what has been explained of the two different views which a near object presents, when looked at successively with the one eye and the other closed, the principle of the stereoscope will be easily understood.

A bust being placed before a competent draughtsman, as above described, at a distance sufficiently small to produce considerable

binocular parallax, let him make two exact drawings of it, one with the right eye closed, and the other with the left eye closed. These two drawings will then represent the object as it is actually seen, when the optic axis of each eye is directed to it. Let us suppose that, by some optical expedient, the two drawings thus made can be so presented to the two eyes, that the optic axis, when directed to them, shall converge at the same angle as when they are directed to the object itself. In that case each eye will obtain the same view which it would obtain if the object itself were placed before it, and the visual perception must necessarily be the same as would be produced by the object looked at with both eyes open.

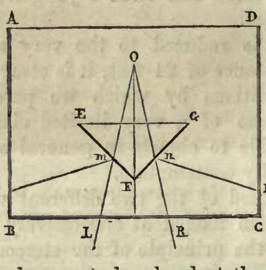
6. Now the optical expedient by which this is accomplished is the *stereoscope*, a name derived from two Greek words, *στερεόν* (stereon), *a solid object*, and *σκοπέω*, (skopeo) *I look at;* inasmuch as the effect is such as to make the observer imagine that a really solid object (in the geometrical sense of the term), instead of a flat surface, is placed before him.

Various optical combinations have been proposed and contrived, for the purpose of producing this effect upon two such drawings as we have here described. In some the visual rays proceeding from the pictures are thrown into the requisite direction by reflection, and in others by refraction.

7. In the first form given to the instrument by Professor Wheatstone, its inventor, the visual rays proceeding from the two pictures were deflected by two plane reflectors placed at a right angle, so that in entering the eyes they proceeded as if they had diverged from a common point, at which the object represented by the pictures would therefore appear to be placed.

Let A B C D (fig. 3) be the ground-plan of a rectangular box, open upon the side A D so as to admit the light.

Fig. 3.



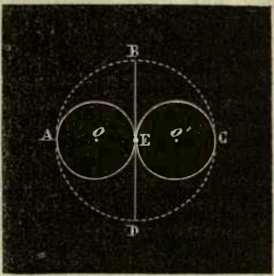
Let R and L be two eye-holes made in the side B C, at a distance apart equal to the distance between the eyes of the observer. Let E F and F G be two plane mirrors placed at right angles to each other. Let a drawing of an object seen with the right eye, the left being closed, be attached to the inside of D C at *r*, and another made from the object seen with the left eye, the right being closed, be in like manner attached at *l* to the inside of A B. Supposing the eyes of the observer to be placed at the holes R and L, the right eye will see by reflection the drawing *r* in the direction R *n*, and the left eye will see the drawing *l* by reflection in the direction L *m*. If the lines L *m* and R *n* be

imagined to be continued backwards, they will meet at a certain point O behind the reflectors; and if the drawings r and l be made to correspond with the views which the right and left eyes would have respectively of the object itself, which they represent, placed at O, the impression produced by the two drawings thus seen will be precisely the same as those which would be produced on the right and left eye respectively by the object itself seen at O.

8. In the lenticular stereoscope invented by Sir David Brewster, the form of the instrument to which the public in general in all countries have given the preference, the visual rays proceeding from the two pictures are deflected and made to diverge from the desired distance, by means of two eccentric double convex lenses.

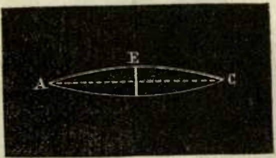
These are formed by cutting a double convex lens A B C D (fig. 4), into two semi-lenses B A D and B C D, in the direction of a plane B D, passing through the centre of the lens. The two eccentric lenses are then cut out of these, so that the diameters A E and C E shall be the semi-diameters of the original lens. It will be evident that a section of the original lens, made by a plane passing through A E C at right angles to its surface, will have the form represented at A E C (fig. 5), and consequently that the two eccentric lenses A E and C E will have their thickest part at E, and their thinnest at A and C. While the geometrical centres of these lenses are at o and o', their optical centres are at the thickest point E of the radius.

Fig. 4.



Now, suppose these two lenses to be set with their edges A and C towards each other in two eye-holes whose distance apart is equal to that of the eyes, and let two objects, P and P′ (fig. 6), be placed before them at a distance equal to their common focal length. According to the properties of lenses already explained, pencils of rays diverging from P and P′, and passing through the lenses, will be, after refraction, parallel respectively to lines drawn from P and P′, through the optical centres E and E′ of the lenses. Thus the visual ray P p will, after refraction, issue in the direction p L, and the ray P′ p' will issue in the direction p' R, so that the points P and P′ will be seen in the directions of L p and R p' converging to the point O.

Fig. 5.

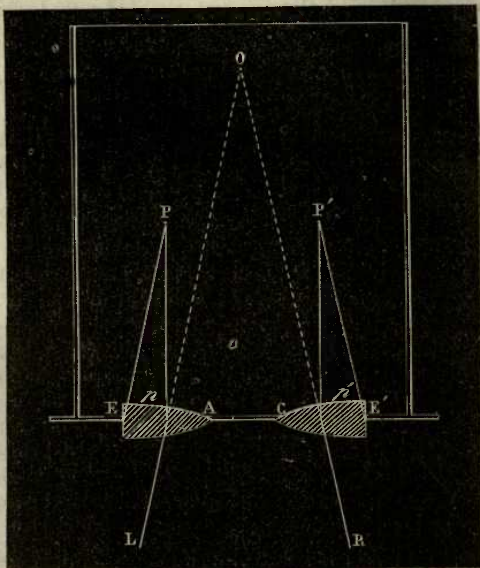


Now, if P be a picture of an object as it appears to the left eye, and P′ a picture of it as it appears to the right eye, these two pictures will be brought together at O by the refraction of the lenses, and the eyes will see the combined pictures at O, exactly as they would see the object itself if it were placed there.

An advantage incidental to this arrangement is, that the

convexity of the lenticular eye-pieces A E and C E′, may be such as to produce any desired magnifying effect, within practical limits, upon the two pictures.

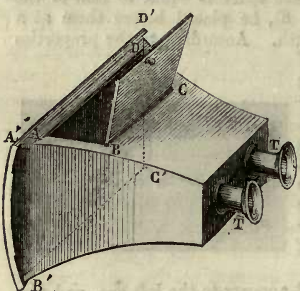
Fig. 6.



The tubes containing the eye-glasses A E and C E′, are made to draw in and out so as to be adapted to different eyes; and they are fixed by pins, which pass into slits made in them in that position in which the deflected rays have the proper degree of divergence.

The form in which this lenticular stereoscope is usually constructed, is shown in fig. 7. The pictures are either opaque or transparent. If they are opaque, they are illuminated through an opening A B C D, covered by a hinged lid, the inside surface of which is coated with tinfoil so as to reflect light upon the pictures. If they are transparent, the base of the instrument A′ B′ C′ D′ has a plate of ground glass set in it, which allows a diffused light to pass through the pictures.

Fig. 7.



9. In what has been stated above, it has been assumed that two drawings of the same object can be produced, differing one from another precisely as the two views of the same object would differ, when viewed by the right and the left eye successively, subject to a given degree of binocular parallax. Now, the difficulty, if

not the total impracticability, of accomplishing this, with the extreme precision which is indispensable, by any process of hand-drawing, will be apparent; and if the stereoscope were dependent on such a process, the most remarkable effects manifested by it would never have been witnessed. Fortunately, however, contemporaneously with this beautiful optical invention, another, still more remarkable, was in progress of improvement. Photography lent its powerful aid to the stereoscope, and supplied an easy and perfectly accurate and efficient means of producing the right and left monocular pictures. If two lines be imagined to be drawn from the object inclined to each other at the angle which measures the proposed binocular parallax, two photographic instruments placed one on each of these lines, at the proper distance from the object, will produce the two desired pictures; or the same instrument would do so, placed successively in the directions of the two lines.

The stereoscopic pictures are accordingly produced by this method either upon daguerreotype plates, photographic paper, or glass. On daguerreotype plates they are necessarily opaque; on glass they are transparent; and on paper may be either opaque or transparent, according to the thickness and quality of the paper.

10. Since the greater number of stereoscopic pictures represent views of objects which must be so distant from the observer as to have no sensible binocular parallax, it may be asked how it is that stereoscopic effects, so remarkable as those which are manifested by such pictures, can be produced. If the stereoscopic effects be the consequences of binocular parallax, and of that alone, how can such effects be produced by pictures of objects, which have no such parallax?

This brings us back to a statement made in the commencement of this notice, that the appearance of perspective and relief produced by the stereoscope is, in most cases, exaggerated, as compared with that produced by an immediate view of the objects themselves, and that it is consequently such as can never be perceived when the objects themselves are looked at; and that hence arises the sensation of surprise that such stereoscopic effects never fail to excite.

If we desire to obtain a pair of stereoscopic pictures of any object of considerable magnitude, a palace or a cathedral, for example, we take a position at such a distance from it as will enable us to obtain, in the camera obscura of the photographic apparatus, a picture of it on a sufficiently small scale. Supposing, then, two lines to be drawn from the centre of the object to the place selected for the camera, making with each other an angle equal to the amount of binocular parallax, which is necessary to produce the stereoscopic effect of perspective and relief; let two

photographic instruments be then placed one on each of these lines, with their optic axes in the directions of the lines respectively, and therefore converging towards the same point of the object, and let the distances of their object glasses from that point be equal. The optical pictures which they will produce will in that case be those which would be seen by two eyes, right and left, having a distance apart equal to the distance between the object glasses of the two photographic instruments.

When the pictures are thus produced on a small scale they are placed in the stereoscope, the eye-glasses of which will have the effect of causing them to be viewed in lines converging at the same angle, as that formed by the optic axes of the two photographic instruments by which the pictures were produced.

11. It will be manifest, then, that the impression produced by the view of such pictures in the stereoscope will be such, as could never be produced by the immediate view of the objects themselves, inasmuch as they could never be seen with any such degree of binocular parallax, as that which has been given to them by the relative position of the two photographic instruments. This parallax will be greater than the natural binocular parallax of the object, in the same proportion as the distance between the centres of the object glasses of the two photographic instruments, is greater than the distance between the eyes. Thus if, in taking such a pair of stereoscopic views of a building, the distance between the photographic instruments is 50 inches, the parallax thus produced will be greater than the natural binocular parallax in the proportion of 50 to 2½, or 20 to 1, and so far as the perception of perspective and relief depends on binocular parallax, that which is produced from viewing the pictures of the building in the stereoscope, will be 20 times more strong and vivid than that which is produced by the view of the building itself, seen from the station at which the pictures are taken.

It is then rigorously true, that the surprise and admiration excited by the stereoscope, does not arise from the truth of the picture which it presents, but from the strong exaggeration of perspective and relief which it exhibits. It is very true that no art of the draughtsman or painter could produce any such effects; but it is equally true that no such effects could be produced by the objects themselves.

Among the most interesting and instructive as well as surprising effects of the stereoscope, are those which it exhibits when stereoscopic views of geometrical solid figures are exhibited in it. The variety of these is endless. But since no mere verbal description could convey any adequate idea of them, we can only invite the reader's attention to this class of objects.

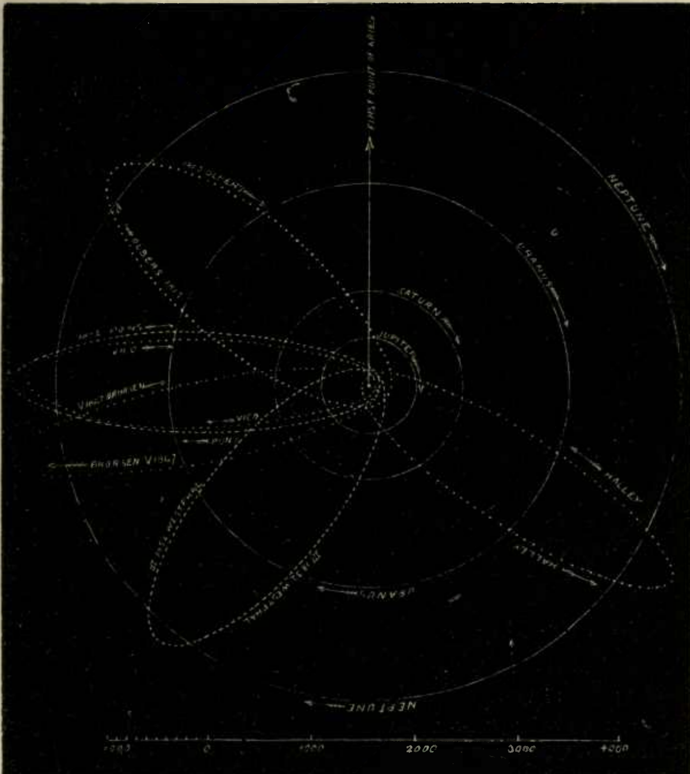


Fig. 5.

COMETS.

CHAPTER I.

I. Cometary Orbits: 1. Prescience of the astronomer.—2. Strikingly illustrated by cometary discovery.—3. Motion of comets explained by gravitation.—4. Conditions imposed on the orbits of bodies which are subject to the attraction of gravitation.—5. Elliptic orbit.—6. Parabolic orbits.—7. Hyperbolic orbits.—8. Planets observe in their motions order not exacted by the law of gravitation.—9. Comets observe no such order in their motions.—10. They move in conic sections, with the sun for the focus.—11. Difficulty of ascertaining in what species of conic section a comet moves.—12. Hyperbolic and parabolic comets not periodic.—13. Elliptic comets periodic like the planets.—14. Difficulties attending the analysis of cometary motions. —15. Periodicity alone proves the elliptic character.—16. Periodicity

combined with the identity of the paths while visible establishes identity.—17. Many comets recorded—few observed.—18. Classification of the cometary orbits.—II. Elliptic Comets revolving within the orbit of Saturn: 19. Encké's comet.—20. Table of the elements of the orbit.—21. Indications of the effects of a resisting medium.—22. The luminiferous ether would produce such an effect.—23. Comets would ultimately fall into the sun.

I.—COMETARY ORBITS.

1. For the civil and political historian the past alone has existence—the present he rarely apprehends; the future never. To the historian of science it is permitted, however, to penetrate the depths of past and future with equal clearness and certainty: facts to come are to him as present, and not unfrequently more assured than facts which are passed. Although this clear perception of causes and consequences characterises the whole domain of physical science, and clothes the natural philosopher with powers denied to the political and moral inquirer, yet foreknowledge is eminently the privilege of the astronomer. Nature has raised the curtain of futurity, and displayed before him the succession of her decrees, so far as they affect the physical universe, for countless ages to come; and the revelations of which she has made him the instrument, are supported and verified by a never-ceasing train of predictions fulfilled. He "shows us the things which will be hereafter," not obscurely shadowed out in figures and in parables, as must necessarily be the case with other revelations, but attended with the most minute precision of time, place, and circumstance. He converts the hours as they roll into an ever-present miracle, in attestation of those laws which his Creator through him has unfolded; the sun cannot rise—the moon cannot wane—a star cannot twinkle in the firmament, without bearing witness to the truth of his prophetic records. It has pleased the "Lord and Governor" of the world, in his inscrutable wisdom, to baffle our inquiries into the nature and proximate cause of that wonderful faculty of intellect—that image of his own essence which he has conferred upon us; nay, the springs and wheelwork of animal and vegetable vitality are concealed from our view by an impenetrable veil, and the pride of philosophy is humbled by the spectacle of the physiologist bending in fruitless ardour over the dissection of the human brain, and peering in equally unproductive inquiry over the gambols of an animalcule. But how nobly is the darkness which envelopes metaphysical inquiries compensated by the flood of light which is shed upon the physical creation! *There* all is harmony, and order, and majesty, and beauty. From the chaos of social and political phenomena exhibited in human records—phenomena

unconnected to our imperfect vision by any discoverable law, a war of passions and prejudices, governed by no apparent purpose, tending to no apparent end, and setting all intelligible order at defiance—how soothing and yet how elevating it is to turn to the splendid spectacle which offers itself to the habitual contemplation of the astronomer! How favourable to the development of all the best and highest feelings of the soul are such objects! the only passion they inspire being the love of truth, and the chiefest pleasure of their votaries arising from excursions through the imposing scenery of the universe—scenery on a scale of grandeur and magnificence, compared with which whatever we are accustomed to call sublimity on our planet dwindles into ridiculous insignificancy. Most justly has it been said, that nature has implanted in our bosoms a craving after the discovery of truth, and assuredly that glorious instinct is never more irresistibly awakened than when our notice is directed to what is going on in the heavens. "Quoniam eadem Natura cupiditatem ingenuit hominibus veri inveniendi, quod facillime apparet, cum vacui curis, etiam quid in cœlo fiat, scire avemus; his initiis inducti omnia vera diligimus; id est, fidelia, simplicia, constantia; tum vana, falsa, fallentia odimus." *

2. Such reflections are awakened by every branch of astronomy, but by none so strongly as by the history of cometary discovery. No where can be found so marvellous a series of phenomena foretold. The interval between the prediction and its fulfilment has sometimes exceeded the limits of human life, and one generation has bequeathed its predictions to another, which has been filled with astonishment and admiration at witnessing their literal accomplishment.

3. In the vast framework of the theory of gravitation constructed by Newton, places were provided for the arrangement and exposition not only of all the astronomical phenomena which the observation of all preceding generations had supplied, but also for a far greater mass which the more fertile and active research of the generations which succeeded him have furnished. By this theory all the known planetary motions were explained, and planets previously unseen were felt by their effects, their places ascertained, and the telescope of the observer guided to them.

But transcendently the greatest triumph of this celebrated theory was the exposition it supplied of the physical laws which govern the motions of comets as distinguished from those which prevail among the planets.

4. It is proved in the propositions demonstrated in the first

* Cic. de Fin. Bon. et Mal., ii. 14.

book of Newton's Principia, which propositions form in substance the ground-work of the entire theory of gravitation, that a body which is under the influence of a central force, the intensity of which decreases as the square of the distance increases, must move in one or other of the curves known to geometers as the "CONIC SECTIONS," being those which are formed by the intersection of the surface of a cone by a plane, and that the centre of attraction must be in the FOCUS of the curve; and in order to prove that such curves are compatible with no other law of attraction, it is further demonstrated that whenever a body is observed to move round a centre of attraction in any one of these curves, that centre being its focus, the law of the attraction will be that of gravitation; that is to say, its intensity will vary in the inverse proportion of the square of the distance of the moving body from the centre of force.

Subject to these limitations, however, a body may move round the sun in any orbit, at any distance, in any plane, and in any direction whatever. It may describe an ellipse of any eccentricity, from a perfect circle to the most elongated oval. This ellipse may be in any plane, from that of the ecliptic to one at right angles to it, and the body may move in such ellipses either in the same direction as the earth or in the contrary direction. Or the body thus subject to solar attraction may move in a parabola with its point of perihelion at any distance whatever from the sun, either grazing its very surface or sweeping beyond the orbit of Neptune, or, in fine, it may sweep round the sun in an hyperbola, entering and leaving the system in two divergent directions.

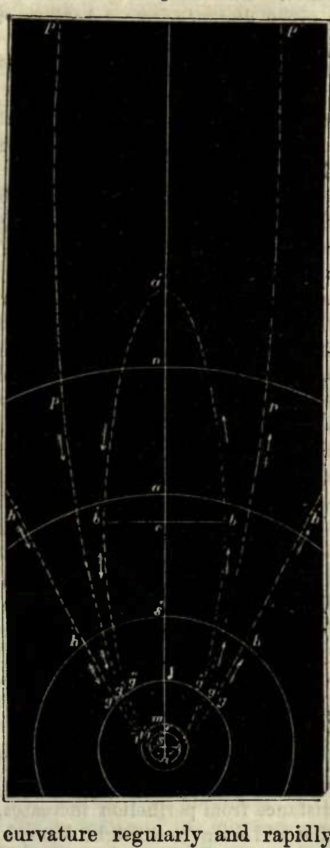
To render these explanations, which are of the greatest interest and importance in relation to the subject of comets, more clearly understood, we have represented, in fig. 1, the forms of a very eccentric ellipse, $a\ b\ a'\ b'$, a parabola $a\ p\ p'$, and an hyperbola $a\ h\ h'$, having s as their common focus, and it will be convenient to explain in the first instance the relative magnitude of some important lines and distances connected with these orbits.

5. Ellipses or ovals vary without limit in their eccentricity. A circle is regarded as an ellipse whose eccentricity is nothing. The orbits of the planets generally are ellipses, but having eccentricities so small that, if described on a large scale in their proper proportions on paper, they would be distinguishable from circles only by measuring accurately the dimensions taken in different directions, and thus ascertaining that they are longer in a certain direction than in another at right angles to it. A very eccentric and oblong ellipse is delineated in fig. 1, of which $a\ a'$ is the major axis. The focus being s, the perihelion distance

d is *s a*, and the aphelion distance *d′* is *s a′*, the mean distance *a* being *s c*, or half the major axis.

The curvature of the ellipse continually increases from the mean distance to perihelion, and constantly decreases from perihelion to the mean distance, being equal at equal angular distances from perihelion as seen from the sun.

Fig. 1.



It is evident that if a body move in a very eccentric ellipse, such as that represented in fig. 1, whose plane coincides exactly or nearly with the common plane of the planetary orbits, it may intersect the orbits of several or all of the planets, as it is represented to do in the figure, although its mean distance from the sun may be less than the mean distance of several of those which it thus intersects. The aphelion distance of such a body may, therefore, greatly exceed that of any planet; while its mean distance may be less than that of the more distant planets.

6. The form of a parabolic orbit having the same perihelion distance as the elliptic orbit is represented at *a p p*, in fig. 1. This orbit consists of two indefinite branches, similar in form, which unite at perihelion *a*. Departing from this point on opposite sides of the axis *a a′*, their curvature regularly and rapidly decreases, being equal at equal distances from perihelion. The two branches have a constant tendency to assume the direction and form of two straight lines parallel to the axis *a a′*. To actual parallelism, and still less to convergence, these branches, however, never attain, and consequently they can never reunite. They extend, in fine, like parallel straight lines, to an unlimited

distance, without ever reuniting, but assuming directions when the distance from the focus bears a high ratio to the perihelion distance, which are practically undistinguishable from parallelism.

One parabolic orbit differs from another in its perihelion distance. The less this distance is, the less will be the separation at a given distance from *s* between the parallel directions to which the indefinite branches *p p'* tend. This distance may have any magnitude. The body in its perihelion may graze the surface of the sun, or may pass at a distance from it greater than that of the most remote of the planets, so that, although it be subject to solar attraction, it would in that case never enter within the limits of the solar system at all.

A body moving in such an orbit, therefore, would not make, like one which moves in an ellipse, a succession of revolutions round the sun; nor can the term periodic time be applied at all to its motion. It enters the system in some definite direction, such as *p' p*, as indicated by the arrow from an indefinite distance. Arriving within the sensible influence of solar gravitation, the effects of this attraction are manifested in the curvation of its path, which gradually increases as its distance from the sun decreases, until it arrives at perihelion, where the attractive force, and consequently the curvature, attain their maxima. The extreme velocity which the body attains at this point produces, in virtue of the inertia of the moving mass, a centrifugal force, which counteracts the gravitation, and the body, after passing perihelion, begins to retreat; the solar gravitation and the curvature of its path decreasing together, until it issues from the system in a direction *p p'*, as indicated by the arrows, which is nearly a straight line, and parallel to that in which it entered. In such an orbit a body therefore visits the system but once. It enters in a certain direction from an indefinite distance, and, passing through its perihelion, issues in a parallel direction, passing to an unlimited distance, never to return.

7. Hyperbolic orbits, like the parabolas, consist of two indefinite branches, which unite at perihelion, which at equal distances from perihelion have equal curvatures, and which, as the distance from perihelion increases, approach indefinitely in direction and form to straight lines, but, unlike the parabolic orbits, the straight lines to whose direction the two branches approximate are divergent and not parallel.

Such an orbit having the same perihelion distance as the ellipse and parabola, is represented by *a h h'*, fig. 1.

The parabola is included between the ellipse and hyperbola.

8. When the theory of gravitation was first propounded by its

illustrious author, no other bodies, save the planets and satellites then discovered, were known to move under the influence of such a central attraction. These bodies, however, supplied no example of the play of that celebrated theory in its full latitude. They obeyed, it is true, its laws, but they did much more. They displayed a degree of harmony and order far exceeding what the law of gravitation exacted. Permitted by that law to move in any of the three classes of conic sections, their paths were exclusively elliptical; permitted to move in ellipses infinitely various in their eccentricities, they moved exclusively in such as differed almost insensibly from circles; permitted to move at distances subordinated to no regular law, they moved in a series of orbits at distances increasing in a regular progression; permitted to move at all conceivable angles with the plane of the ecliptic, their paths are inclined to it at angles limited in general to a few degrees; permitted, in fine, to move in either direction, they all agreed in moving in the direction in which the earth moves in its annual course.

Accordance so wondrous, and order so admirable, could not be fortuitous, and, not being enjoined by the conditions of the law of gravitation, must either be ascribed to the immediate dictates of the Omnipotent Architect of the universe above all general laws, or to some general laws superinduced upon gravitation, which had escaped the sagacity of the discoverer of that principle. If the former supposition were adopted, some bodies, different in their physical characters from the planets, primary and secondary, playing different parts and fulfilling different functions in the economy of the universe, might still be found, which would illustrate the play of gravitation in its full latitude, sweeping round the sun in all forms of orbit, eccentric, parabolic, and hyperbolic, in all planes, at all distances, and indifferently in both directions. If the latter supposition were accepted, then no other orbit, save ellipses of small eccentricity, with planes coinciding nearly with that of the ecliptic, would be physically possible.

9. The theory of gravitation had not long been promulgated, nor as yet been generally accepted, when the means of its further verification were sought in the motion of comets. Hitherto these bodies had been regarded as exceptional and abnormal, and as being exempt altogether from the operation of the law and order which prevailed in a manner so striking among the members of the solar system. So little attention had been given to comets that it had not been certainly ascertained whether they were to be classed as meteoric or cosmical phenomena; whether their theatre was the regions of the atmosphere, or the vast spaces in which the great bodies of the universe move. Their apparent positions in

the heavens on various occasions of the appearances of the most conspicuous of them had nevertheless been from time to time for some centuries observed and recorded with such a degree of precision as the existing state of astronomical science permitted; and even when their places were not astronomically ascertained, the date of their appearance was generally preserved in the historic records, and in many cases the constellations through which they passed were indicated, so that the means of obtaining at least a rude approximation to their position in the firmament were thus supplied.

10. Such observations, vague, scattered, and inexact as they were, supplied, however, data by which, in several cases, it was possible to compute the real motion of these bodies through space, their positions in relation to the sun, the earth, and the planets, and the paths they followed in moving through the system, with sufficiently approximate accuracy to conclude with certainty that they were one or other of the conic sections, the place of the sun being the focus.

This was sufficient to bring these bodies under the general operation of the attraction of gravitation.

It still remained, however, to determine more exactly the specific character of these orbits. Are they ellipses more or less eccentric? or parabolas? or hyperbolas?—Any of the three classes of orbits would, as has been shown, be equally compatible with the law of gravitation.

11. It might be supposed that the same course of observation as that by which the orbit of a planet is traced would be applicable equally to comets. Many circumstances, however, attend this latter class of bodies, which render such observations impossible, and compel the astronomer to resort to other means to determine their orbits.

A spectator stationed upon the earth keeps within his view each of the other planets of the system throughout nearly the whole of its course. Indeed, there is no part of the orbit of any planet in which, *at some time or other*, it may not be seen from the earth. Every point of the path of each planet can therefore be observed; and, although without waiting for such observation, its course might be determined, yet it is material here to attend to the fact, that the whole orbit may be submitted to direct observation. The different planets, also, present peculiar features by which each may be distinguished. Thus, as has been explained, they are observed to be spherical bodies of various magnitudes. Their surfaces are marked by peculiar modes of light and shade, which, although variable and shifting, still, in each case, possess some prevailing and permanent characters by which the identity of the

object may be established, even were there no other means of determining it.

Unlike planets, comets do not present to us those individual characters above mentioned, by which their identity may be determined. None of them have been satisfactorily ascertained to be spherical bodies, nor indeed to have any definite shape. It is certain that many of them possess no solid matter, but are masses consisting of some nearly transparent substances; others are so surrounded with this apparently vaporous matter, that it is impossible, by any means of observation which we possess, to discover whether this vapour enshrouds within it any solid mass. The same vapour which thus envelopes the body (if such there be within it) also conceals from us its features and individual character. Even the limits of the vapour itself, if vapour it be, are subject to great change in each individual comet. Within a few days they are sometimes observed to increase or diminish some hundred-fold. A comet appearing at distant intervals presents, therefore, no very obvious means of recognition. A like extent of surrounding vapour would evidently be a fallible test of identity; and not less inconclusive would it be to infer diversity from a different extent of nebulosity.

If a comet, like a planet, revolved round the sun in an orbit nearly circular, it might be seen in every part of its path, and its identity might thus be established independently of any peculiar characters in its appearance. But such is not the course which comets are observed to take.

In general a comet is visible only throughout an arc of its orbit, which extends to a certain limited distance on each side of its perihelion. It first becomes apparent at some point of its path, such as g, g' or g'', fig. 1; it approaches the sun and disappears after it passes a corresponding point g, g' or g'' in departing from the sun. The arc of its orbit in which alone it is visible would therefore be $g\ a\ g$, $g'\ a\ g'$, or $g''\ a\ g''$.

If this arc, extending on either side of perihelion, could always be observed with the same precision as are the planetary orbits, it would be possible, by the properties of the conic sections, to determine not only the general character of the orbit, whether it be an ellipse, or parabola, or an hyperbola, but even to ascertain the individual curve of the one kind or the other in which the comet moves, so that the course it followed before it became visible, as well as that which it pursues after it ceases to be visible, would be as certainly and precisely known as if it could be traced by direct observation throughout its entire orbit.

12. If it be ascertained that the arc in which the comet moves while it is visible is part of an hyperbola, such as $g\ a\ g$, it will be

inferred that the comet coming from some indefinitely distant region of the universe, has entered the system in a certain direction, $h' h$, which can be inferred from the visible arc $g a g$, and that it must depart to another indefinitely distant region of the universe following the direction $h h'$, which is also ascertained from the visible arc $g a g$.

If, on the other hand, it be ascertained that the visible arc, such as $g' a g'$, be part of a parabola, then, in like manner by the properties of that curve, it will follow that it entered the system coming from an indefinitely distant region of the universe in a certain direction, $p' p$, which can be inferred from the visible arc $g' a g'$, and that after it ceases to be visible, it will issue from the system in another determinate direction, $p p'$, parallel to that by which it entered.

The comet, in neither of these cases, would have a periodic character. It would be analogous to one of those occasional meteors which are seen to shoot across the firmament never again to reappear. The body arriving from some distant region, and coming, as would appear, fortuitously within the solar attraction, is drawn from its course into the hyperbolic or parabolic path, which it is seen to pursue, and escapes from the solar attraction, issuing from the system never to return. The phenomenon would in each case be occasional, and, in a certain sense, accidental, and the body could not be said properly to belong to the system. So far as relates to the comet itself, the phenomenon would consist in a change of the direction of its course through the universe, operated by the temporary action of solar gravitation upon it.

13. But the case is very different, the tie between the comet and the system much more intimate, and the interest and physical importance of the body transcendently greater when the arc, such as $g'' a g''$, proves to be part of an ellipse. In that case, the invisible part of the orbit being inferred from the visible, the major axis $a a'$ would be known. The comet would possess the periodic character, making successive revolutions like the planets, and returning to perihelion a after the lapse of its proper periodic time, which could be inferred by the harmonic law from the magnitude of its major axis.

Such a body would then not be, like those which follow hyperbolic or parabolic paths, an occasional visit to the system, connected with it by no permanent relation, and subject to solar gravitation only accidentally and temporarily. It would, on the contrary, be as permanent, if not as strictly regular, a member of the system as any of the planets, though invested, as will presently appear, with an extremely different physical character.

It will therefore be easily conceived with what profound interest

comets were regarded before the theory of gravitation had been yet firmly established or generally accepted, and while it was, so to speak, upon its trial. These bodies were, in fact, looked for as the witnesses whose testimony must decide its fate.

14. Difficulties, however, which seemed almost insurmountable, opposed themselves to a satisfactory and conclusive analysis of their motions. Many causes rendered the observations upon their apparent places few in number and deficient in precision. The arcs $g\ a\ g$, $g'\ a\ g'$, and $g''\ a\ g''$ of the three classes of orbit in any of which they might move without any violation of the law of gravitation were very nearly coincident in the neighbourhood of the place of perihelion a. It was, for example, in almost all the cases which presented themselves, possible to conceive three different curves, an eccentric ellipse, such as $a\ b\ a'\ b'$, a parabola, such as $p'\ p\ a$, and an hyperbola, such as $h'\ h\ a$, so related that the arcs $g\ a\ g$, $g'\ a\ g'$, and $g''\ a\ g''$, would not deviate one from another to an extent exceeding the errors inevitable in cometary observations. Thus any one of the three curves within the limits of the visible path of the comet might with equal fidelity represent its course. In such cases, therefore, it was impossible to infer, from the observations alone, whether the comet belonged to the class of hyperbolic or parabolic bodies, which have no periodic character, or to the elliptic, which has.

15. The character of periodicity itself, which belongs exclusively to elliptic orbits, supplied the means of surmounting this difficulty. If any observed comet have an elliptic motion, it must return to perihelion after completing its revolution, and it must have been visible on former returns to that position. Not only ought it to be expected, therefore, that such a comet would re-appear in future after absences of equal duration (depending on its periodic time), but that its previous returns to perihelion would be found by searching among the recorded appearances of such objects for any, the dates of whose appearance might correspond with the supposed period, and whose apparent motions, if observed, might indicate a real motion in an orbit, identical or nearly so with that of the comet in question.

If the motion of such a body were not affected by any other force except the solar attraction, it would re-appear after each successive revolution at exactly the same point; would follow, while visible, exactly the same arc $g''\ a\ g''$; would move in the same plane, inclined at the same angle to the ecliptic, the nodes retaining the same places; and would arrive at its perihelion at exactly the same point a, and after exactly equal intervals.

Now, although the disturbing actions of the planets near which it might pass, in departing from and returning to the sun, must

be expected to be much more considerable than when one planet acts upon another, as well because of the extreme comparative lightness of the comet, as of the great eccentricity of its orbit, which sometimes actually or nearly intersects the paths of several planets, and especially those of the larger ones, yet still such planetary attractions are *only* disturbances, and cannot be supposed to efface that character which the orbit receives from the predominant force of the immense mass of the sun. While therefore we may be prepared for the possibility, and even the probability, that the same periodic comet on the occasion of its successive re-appearances, may follow a path $g'' \, a \, g''$ in passing to and from its perihelion, differing to some extent from that which it had followed on previous appearances, yet in the main such differences cannot, except in rare and exceptional cases, be very considerable, and for the same reason the intervals between its successive periods, though they may differ, cannot be subject to any very great variation.

16. If then, on examining the various comets whose appearances have been recorded, and whose places while visible have been observed, and on computing from the apparent places the arc of the orbit through which they moved, it be found that two or more of them, while invisible, moved in the same path, the presumption will be that these were the same body re-appearing after having completed its motion in an elliptic orbit; nor should this presumption of identity be hastily rejected because of the existence of any discrepancies between the observed paths, or any inequality of the intervals between its successive re-appearances, so long as such discrepancies can fairly be ascribed to the possible disturbances produced by planets which the comet might have encountered in its path.

17. Many comets, however, have been *recorded*, but not *observed*. Historians have mentioned, and even described, their appearances, and in some cases have indicated the chief constellations through which such bodies passed, although no observations of their apparent places have been transmitted by which any close approximation to their actual paths could be made. Nevertheless, even in these cases, some clue to their identification is supplied. The intervals between their appearances alone is a highly probable test of identity. Thus if comets were regularly recorded to have appeared at intervals of fifty years (no circumstance affording evidence of the diversity of these objects), they might be assumed, with a high degree of probability, to be the successive returns of an elliptic comet having that interval as its period.

18. The appearances of about 400 comets had been recorded in the annals of various countries before the end of the seventeenth

century, the epoch signalised by the discoveries and researches of Newton. In most cases, however, the only circumstance recorded was the appearance of the object, accompanied in many instances with details bearing evident marks of exaggeration respecting its magnitude, form, and splendour. In some few cases, the constellations through which the object passed successively, with the necessary dates, are mentioned, and in some, fewer still, observations of a rough kind have been handed down. From such scanty data, eagerly sought for in the works preserved in different countries, sufficient materials have been collected for the computation, with more or less approximation, of the elements of the orbits of about sixty of the 400 comets above mentioned.

Since the time of Newton, Halley, and their contemporaries, observers have been more active, and have had the command of instruments of considerable and constantly increasing power; so that every comet which has been visible from the northern hemisphere of the earth since that time, has been observed with continually increasing precision, and data have been in all cases obtained, by which the elements of the orbits have been calculated. Since the year 1700, accordingly, about 140 have been observed, the elements of the orbits of which have been ascertained with great precision.

It appears, therefore, that of the entire number of comets which have appeared in the firmament, the orbits of about 200 have been ascertained. Of this number forty have been ascertained, some conclusively, others with more or less probability, to revolve in elliptic orbits.

Seven have passed through the system in hyperbolas, and consequently will not visit it again, unless they be thrown into other orbits by some disturbing force.

One hundred and sixty have passed through the system either in parabolic orbits, or in ellipses of such extreme eccentricity as to be undistinguishable from parabolas by any data supplied by the observations.

II.—ELLIPTIC COMETS REVOLVING WITHIN THE ORBIT OF SATURN.

19. In 1818, a comet was observed at Marseilles, on the 26th of November, by M. Pons. In the following January, its path being calculated, M. Arago immediately recognised it as identical with one which had appeared in 1805. Subsequently, M. Encké of Berlin succeeded in calculating its entire orbit—inferring the invisible from the visible part—and found that its period was

about 1200 days. This calculation was verified by the fact of its return in 1822, since which time the comet has gone by the name of *Enckė's comet*, and returned regularly.

It may be asked, How it could have happened that a comet which made its revolution in a period so short as three years and a quarter, should not have been observed until so recent an epoch as 1818? This is explained by the fact that the comet is so small, and its light so feeble even when in the most favourable position, that it can only be seen with the aid of the telescope, and not even with this except under certain conditions which are not fulfilled on the occasion of every perihelion passage. Nevertheless, the comet was observed on three former occasions, and the general elements of its path recorded, although its elliptic, and consequently periodic character, was not recognised.

On comparing, however, the elements then observed with those of the comet now ascertained, no doubt can be entertained of their identity.

20. In the following table are given the elements of the orbit of this comet, as computed from the observations made upon it at each of its three appearances in 1786, 1795, and 1805, before its periodic character was discovered, and at its eleven subsequent appearances up to 1852.

TABLE I.

Elements of the Orbit of Enckė's Comet to 1852.

	Mean Distance, Earth's = 1.	Eccentricity.	Perihelion Distance.	Aphelion Distance.	Longitude of Perihelion.			Longitude of Ascending Node.			Inclination.			Time of Perihelion Passage.		
	a	e	$d'=a\times(1-e)$	$d''=a\times(1+e)$	π			ν			i					
					°	′	″	°	′	″	°	′	″		h.	m.
1786	2·2080	0·8484	0·3348	4·0812	156	38	0	334	8	0	13	36	0	Jan. 30.	21	7
1795	2·2130	0·8489	0·3344	4·0916	156	41	20	334	39	22	13	42	30	Dec. 21.	10	44
1805	2·2131	0·8462	0·3404	4·0860	156	47	24	334	20	10	13	33	30	Nov. 21.	12	9
1819	2·2141	0·8486	0·3353	4·0929	156	59	12	334	33	19	13	36	54	Jan. 27.	6	18
1822	2·2244	0·8445	0·3460	4.1028	157	11	44	334	25	9	13	20	17	May 23.	23	16
1825	2·2233	0·8449	0·3449	4·1017	157	14	31	334	27	30	13	21	24	Sept. 16.	6	43
1829	2·2239	0·8446	0·3455	4·1023	157	17	53	334	29	32	13	20	34	Jan. 9.	18	3
1832	2·2219	0·8454	0·3435	4·1003	157	21	1	334	32	9	13	22	9	May 23.	23	34
1835	2·2227	0·8450	0·3444	4·1010	157	23	29	334	34	59	13	21	15	Aug. 26.	8	49
1838	2·2222	0·8452	0·3440	4·1004	157	27	4	334	36	41	13	21	28	Dec. 19.	0	27
1842	2·2229	0·8448	0·3450	4·0998	157	29	27	334	39	10	13	20	26	April 12.	0	35
1845	2·2215	0·8474	0.3381	4·1049	157	44	21	334	19	34	13	7	34	Aug. 9.	15	11
1848	2·2147	0·8478	0·3371	4·0923	157	47	8	334	22	12				Nov. 26.	3+	0
1852	2·2152	0·8477	0·3374	4·0930	157	51	2	334	23	21	13	7	55	March 14.	20	
														M. T. B.		

The motion of this comet is direct; and its period in 1852 was 3·29616 years, which is subject to a slight variation.

It is evident that between 1786 and 1795 there were two,

between 1795 and 1805 two, and, in fine, between 1805 and 1819 three, unobserved returns to perihelion.

It appears, therefore, that, excepting the oval form of the orbit, the motion of this body differs in nothing from that of a planet whose mean distance from the sun is that of the nearest of the planetoids. Its eccentricity is such, however, that when in perihelion it is within the orbit of Mercury, and when in aphelion it is outside the most distant of the planetoids, and at a distance from the sun equal to four-fifths of that of Jupiter.

21. A fact altogether anomalous in the motions of the bodies of the solar system, and indicating a consequence of the highest physical importance, has been disclosed in the observation of the motion of this comet. It has been found that its periodic time, and consequently its mean distance, undergoes a slow, gradual, and apparently regular decrease. The decrease is small, but not at all uncertain. It amounted to about a day in ten revolutions, a quantity which could not by any means be placed to the account either of errors of observation or of calculation; and, besides, this increase is incessant, whereas errors would affect the result sometimes one way and sometimes the other. The period of the comet between 1786 and 1795 was $1208\frac{1}{9}$ days; between 1795 and 1805 it was $1207\frac{9}{10}$ days; between 1805 and 1819 it was $1207\frac{4}{10}$ days; in 1845 it was $1205\frac{1}{4}$ days; and, in fine, in 1852 it was 1204 days.

The magnitude of the orbit thus constantly decreasing (for the cube of its greater axis must decrease in the same proportion as the square of the period), the actual path followed by the comet must be a sort of elliptic spiral, the successive coils of which are very close together, every successive revolution bringing the comet nearer and nearer to the sun.

Such a motion could not arise from the disturbing action of the planets. These forces have been taken strictly into account in the computation of the ephemerides of the comet, and there is still found this residual phenomenon, which cannot be placed to their account, but which is exactly the effect which would arise from any physical agency by which the tangential motion of the comet would be feebly but constantly resisted. Such an agency, by diminishing the tangential velocity, would give increased efficacy to the solar attraction, and, consequently, increased curvature to the comet's path; so that, after each revolution, it would revolve at a less distance from the centre of attraction.

22. It is evident that a resisting medium, such as the luminiferous ether * is assumed to be in the hypothesis which forms

* See "Hand-Book of Astronomy," § 1225.

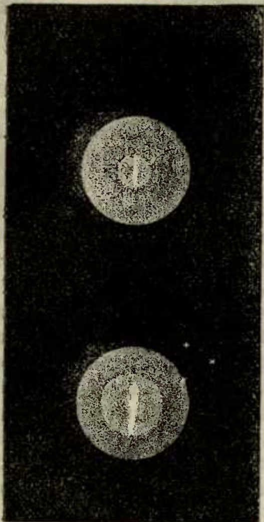
the basis of the undulatory theory of light, would produce just such a phenomenon, and accordingly the motion of this comet is regarded as a strong evidence tending to convert that hypothetical fluid into a real physical agent.

It remains to be seen whether a like phenomenon will be developed in the motion of other periodic comets. The discovery of these bodies, and the observation of their motions, are as yet too recent to enable astronomers, notwithstanding their greatly multiplied number, to pronounce decisively upon it.

23. If the existence of this resisting medium should be established by its observed effects on comets in general, it will follow, that, after the lapse of a certain time (many ages, it is true, but still a definite interval), the comets will be successively absorbed by the sun, unless, as is not improbable, they should be previously vaporised by their near approach to the solar fires, and should thus be incorporated with his atmosphere.

In the efforts by which the human mind labours after truth, it is curious to observe how often that desired object is stumbled upon by accident, or arrived at by reasoning which is false. One of Newton's conjectures respecting comets was, that they are "the aliment by which suns are sustained;" and he therefore concluded that these bodies were in a state of progressive decline upon the suns, round which they respectively swept; and that into these suns they from time to time fell. This opinion appears to have been cherished by Newton to the latest hours of his life: he not only consigned it to his immortal writings, but, at the age of eighty-three, a conversation took place between him and his nephew on this subject, which has come down to us. "I cannot say," said Newton, "when the comet of 1680 will fall into the sun; possibly after five or six revolutions; but whenever that time shall arrive, the heat of the sun will be raised by it to such a point, that our globe will be burnt, and all the animals upon it will perish. The new stars observed by Hipparchus, Tycho, and Kepler, must have proceeded from such a cause, for it is impossible otherwise to explain their sudden splendour." His nephew then asked him, "Why, when he stated in his writings that comets would fall into the sun, did he not also state those vast fires they must produce, as he supposed they had done in the stars?" —"Because," replied the old man, "the conflagrations of the sun concern us a little more directly. I have said, however," added he, smiling, "enough to enable the world to collect my opinion."

Fig. 19.—Jan. 24, 1836. Fig. 21.—Jan. 26, 1836.



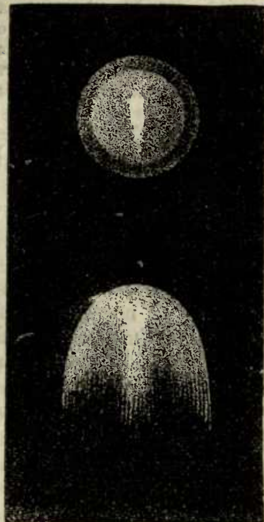


Fig. 20.—Jan. 25, 1836. Fig. 22.—Jan. 27, 1836.

HALLEY'S COMET DEPARTING FROM THE SUN IN 1836.

COMETS.

CHAPTER II.

24. Why like effects are not manifested in the motion of the planets.—25. Corrected estimate of the mass of Mercury.—26. Biela's comet.—27. Possibility of the collision of Biela's comet with the earth.—28. Resolution of Biela's comet into two.—29. Changes of appearance attending the separation.—30. Faye's comet.—31. Reappearance in 1850-1 calculated by M. Le Verrier.—32. De Vico's comet.—33. Brorsen's comet.—34. D'Arrest's comet.—35. Elliptic comet of 1743.—36. Elliptic comet of 1766.—37. Lexell's comet.—38. Analysis of Laplace applied to Lexell's comet.—39. Its orbit before 1767 and after 1770 calculated by his formulæ.—40. Revision of these researches by M. Le Verrier.—41. Process by which the identification of periodic comets may be decided.—42. Application of this process by M. Le Verrier to the comets of Faye, De Vico, and Brorsen, and that of Lexell—their diversity proved.—43. Probable identity of De Vico's comet with the

comet of 1678.—44. Blainplan's comet of 1819.—45. Pons's comet of 1819.—46. Pigott's comet of 1783.—47. Peters's comet of 1846.—48. Tabular synopsis of the orbits of the comets which revolve within Saturn's orbit.—49. Diagram of the orbits.—50. Planetary character of their orbits.—III. Elliptic Comets, whose mean distances are nearly equal to that of Uranus : 51. Comets of long periods first recognised as periodic.—52. Newton's conjectures as to the existence of comets of long periods.—53. Halley's researches.—54. Halley predicts its re-appearance in 1758-9.

24. It may be asked, If the existence of a resisting medium be admitted, whether the same ultimate fate must not await the planets? To this inquiry it may be answered that, within the limits of past astronomical record, the ethereal medium, if it exist, has had no sensible effect on the motion of any planet. That it might have a perceptible effect upon comets, and yet not upon planets, will not be surprising, if the extreme lightness of the comets compared with their bulk be considered. The effect in the two cases may be compared to that of the atmosphere upon a piece of swan's down and upon a leaden bullet moving through it. It is certain that whatever may be the nature of this resisting medium, it will not, for many hundred years to come, produce the slightest perceptible effect upon the motions of the planets.

25. The masses of comets in general are, as will be explained, incomparably smaller than those of the smallest of the planets; so much so, indeed, as to bear no appreciable ratio to them. A consequence of this is, that while the effects of their attraction upon the planets are altogether insensible, the disturbing effects of the masses of the planets upon them are very considerable. These disturbances, being proportional to the disturbing masses, may then be used as measures of the latter, just as the movement of the pith-ball in the balance of torsion supplies a measure of the physical forces to which that instrument is applied.

Encké's comet, near its perihelion, passes near the orbit of Mercury; and when that planet, at the epoch of its perihelion, happens to be near the same point, a considerable and measurable disturbance is manifested in the comet's motion, which being observed, supplies a measure of the planet's mass.

This combination of the motions of the planet and comet took place under very favourable circumstances, on the occasion of the perihelion passage of the comet in 1838, the result of which, according to the calculations of Professor Encké, was the discovery of an error of large amount in the previous estimates of the mass of the planet. After making every allowance for other planetary attractions, and for the effects of the resisting medium, the existence of which it appears necessary to admit, it was inferred

that the mass assigned to Mercury by Laplace was too great in the proportion of 12 to 7.

This question is still under examination, and every succeeding perihelion passage of the comet will increase the data by which its more exact solution may be accomplished.

26. On February 28, 1826, M. Biela, an Austrian officer, observed in Bohemia a comet, which was seen at Marseilles at about the same time by M. Gambart. The path which it pursued, was observed to be similar to that of comets which had appeared in 1772 and 1806. Finally, it was found that this body moved round the sun in an oval orbit, and that the time of its revolution was about 6 years and 8 months. It has since returned at its predicted times, and has been adopted as a member of our system, under the name of Biela's comet.

Biela's comet moves in an orbit whose plane is inclined at a small angle to those of the planets. It is but slightly oval, the length being to the breadth in the proportion of about 4 to 3. When nearest to the sun, its distance is a little less than that of the earth; and when most remote from the sun, its distance somewhat exceeds that of Jupiter. Thus it ranges through the solar system, between the orbits of Jupiter and the earth.

This comet had been observed in 1772 and in 1806; but the elliptic form of its orbit, and consequently its periodicity, was not discovered. Its return to perihelion was predicted and observed in 1832, in 1846, and in 1852; but that which took place in 1838 escaped observation, owing to its unfavourable position and extreme faintness.

A Table, showing the elements of this comet during each of its appearances from 1772 to 1846 inclusive, may be seen by reference to my "Hand-Book of Astronomy."

27. One of the points at which the orbit of Biela's comet intersects the plane of the ecliptic, is at a distance from the earth's orbit less than the sum of the semi-diameters of the earth and the comet. It follows, therefore (2905), that if the comet should arrive at this point at the same moment at which the earth passes through the point of its orbit which is nearest to it, a portion of the globe of the earth must penetrate the comet.

It was estimated on the occasion of the perihelion passage of this comet in 1832, that the semi-diameter of the comet (that body being nearly globular, and having no perceptible tail) was 21000 miles, while the distance of the point at which its centre passed through the plane of the ecliptic, on the 29th October in that year, from the path of the earth was only 18600 miles. If the centre of the earth happened to have been at the point of its orbit nearest to the centre of the comet on that day, the distance

between the centres of the two bodies would have been only 18600 miles, while the semi-diameter of the comet was 21000 miles; and the semi-diameter of the earth being in round numbers 4000 miles, it would follow that in such a contingency the earth would have plunged into the comet to a depth of

$$21000 + 4000 - 18600 = 6400 \text{ miles,}$$

a depth exceeding three-fourths of the earth's diameter.

The possibility of such a catastrophe having been rumoured, great popular alarm was excited before the expected return of the comet in 1832. It was, however, shown that on the 29th October the earth would be about five millions of miles from the point of danger, and that, on the arrival of the earth at that point, the comet would have moved to a still greater distance.

28. *Resolution of Biela's comet into two.*—One of the most extraordinary phenomena of which the history of astronomy affords any example, attended the appearance of this comet in 1846. It was on that occasion seen to resolve itself into two distinct comets, which, from the latter end of December, 1845, to the epoch of its disappearance in April, 1846, moved in distinct and independent orbits. The paths of these two bodies were in such optical juxtaposition that both were always seen together in the field of view of the telescope, and the greatest visual angle between their centres did not amount at any time to 10′, the variation of that angle arising principally from the change of direction of the visual line, relatively to the line joining their centres, and to the change of the comet's distance from the earth.

M. Plantamour, director of the Observatory of Geneva, calculated the orbits of these two comets, considered as independent bodies; and found that the real distance between their centres was, subject to but little variation while visible, about thirty-nine semi-diameters of the earth, or two-thirds of the moon's distance. The comets moved on thus side by side, without manifesting any reciprocal disturbing action; a circumstance no way surprising, considering the infinitely minute masses of such bodies.

29. The original comet was apparently a globular mass of nebulous matter, semi-transparent at its very centre, no appearance of a tail being discoverable. After the separation, both comets had short tails, parallel in their direction, and at right angles to the line joining their centres; both had nuclei. From the day of their separation the original comet decreased, and the companion increased, in brightness, until (on the 10th February) they were sensibly equal. After this the companion still increased

in brightness, and from the 14th to the 16th was not only greatly superior in brightness to the original, but had a sharp and star-like nucleus, compared to a diamond spark. The change of brightness was now reversed, the original comet recovering its superiority, and acquiring on the 18th the same appearance as the companion had from the 14th to the 16th. After this the companion gradually faded away, and disappeared previously to the final disappearance of the original comet on 22nd April.

It was observed also that a thin luminous line or arc was thrown across the space which separated the centres of the two nuclei, especially when one or the other had attained its greatest brightness, the arc appearing to emanate from that which for the moment was the brighter.

After the disappearance of the companion, the original comet threw out three faint tails, forming angles of 120° with each other, one of which was directed to the place which had been occupied by the companion.

It is suspected that the faint comet which was observed by Professor Secchi to precede Biela's comet in 1852, may have been the companion thus separated from it, and if so, the separation must be permanent, the distance between the parts being greater than that which separates the earth from the sun.

30. On the 22nd November, 1843, M. Faye, of the Paris Observatory, discovered a comet, the path of which soon appeared to be incompatible with the parabolic character. Dr. Goldschmidt showed that it moved in an ellipse of very limited dimensions, with a period of $7\frac{1}{2}$ years. It was immediately observed as being extraordinary, that, notwithstanding the frequent returns to perihelion which such a period would infer, its previous appearances had not been recorded. M. Faye replied by showing that the aphelion of the orbit passed very near to the path of Jupiter, and that it was possible that the violent action of the great mass of that planet, in such close proximity with the comparatively light mass of the comet, might have thrown the latter body into its present orbit, its former path being either a parabola or an ellipse, with such elements as to prevent the comet from coming within visible distance. M. Faye supported these observations by reference to a more ancient comet, which we shall presently notice, to which a like incident is supposed with much probability, if not certainty, to have occurred.

31. The observations which had been made in 1843, at several observatories, but more especially those made by M. Struve at Pultowa, who continued to observe the comet long after it ceased to be observed elsewhere, supplied to M. Le Verrier the data necessary for the calculation of its motion in the interval between its

perihelion in 1843 and its expected re-appearance in 1850-1, subject to the disturbing action of the planets, and he predicted its succeeding perihelion for the 3rd of April, 1851.

Aided by the formulæ of M. Le Verrier, Lieutenant Stratford calculated a provisional ephemeris in 1850, by which observers might be enabled more easily to detect the comet, which was the more necessary as the object is extremely faint and small, and not capable of being seen except by means of the most perfect telescopes. By means of this ephemeris, Professor Challis, of Cambridge, found the comet on the night of the 28th November very nearly in the place assigned to it in the tables. Two observations only were then made upon it, which, however, were sufficient to enable M. Le Verrier to give still greater precision to his formulæ, by assigning a definite numerical value to a small quantity which before was left indeterminate. Lieutenant Stratford, with the formula thus corrected, calculated a more extensive and exact ephemeris, extending to the last day of March, and published it in January, 1851, in the Nautical Almanack.

The comet, though extremely faint and small, and consequently difficult of observation, continued to be observed by Professor Challis, with the great Northumberland telescope, at Cambridge, and by M. Struve at Pultowa, and it was found to move in exact accordance with the predictions.

32. On the 22nd August, 1844, M. de Vico, of the Roman Observatory, discovered a comet whose orbit was soon afterwards proved by M. Faye to be an ellipse of moderate eccentricity, with a period of about $5\frac{1}{2}$ years. It arrived at its perihelion on the 2nd of September, and continued to be observed until the 7th of December.

33. On the 26th of February, 1846, M. Brorsen, of Kiel, discovered a faint comet, which was soon found to move in an elliptic orbit, with a period of about $5\frac{1}{2}$ years. Its position in the heavens not being favourable, the observations upon it were few, and the resulting elements, consequently, not ascertained with all the precision that might be desired. Its re-appearance on its approach to the succeeding perihelion, was expected from September to November, 1851. It escaped observation, however, owing to its unfavourable position in relation to the sun. Its next perihelion passage will take place in 1857.

34. On the 27th of June, 1851, Dr. d'Arrest, of the Leipsic Observatory, discovered a faint comet, which M. Villarceaux proved to move in an elliptic orbit, with a period of about $6\frac{1}{2}$ years. The next perihelion passage of this comet will take place in the end of 1857, or the beginning of 1858.

35. A revision of the recorded observations of former comets by

the more active and intelligent zeal of modern mathematicians and computers, has led to the discovery of the great probability of several among them having revolved in elliptic orbits, with periods not differing considerably from those of the comets above mentioned. The fact that these comets have not been re-observed on their successive returns through perihelion, may be explained, either by the difficulty of observing them, owing to their unfavourable positions, and the circumstance of observers not expecting their re-appearance, their periodic character not being then suspected; or because they may have been thrown by the disturbing action of the larger planets into orbits such as to keep them continually out of the range of view of terrestrial observers.

Among those may be mentioned a comet which appeared in 1743, and was observed by Zanetti at Bologna; the observations indicate an elliptic orbit, with a period of about 5½ years.

36. This comet, which was observed by Messier, at Paris, and by La Nux, at the Isle of Bourbon, revolved, according to the calculations of Burckhardt, in an ellipse with a period of 5 years.

37. The history of astronomy has recorded one singular example of a comet which appeared in the system, made two revolutions round the sun in an elliptic orbit, and then disappeared, never having been seen either before or since.

This comet was discovered by Messier, in June 1770, in the constellation of Sagittarius, between the head and the northern extremity of the bow, and was observed during that month. It disappeared in July, being lost in the sun's rays. After passing through its perihelion, it re-appeared about the 4th of August, and continued to be observed until the first days of October, when it finally disappeared.

All the attempts of the astronomers of that day failed to deduce the path of this comet from the observations, until six years later, in 1776, Lexell showed that the observations were explained, not, as had been assumed previously, by a parabolic path, but by an ellipse, and one, moreover, without any example at that epoch, which indicated the short period of 5½ years.

It was immediately objected to such a solution, that its admission would involve the consequence that the comet, with a period so short, and a magnitude and splendour such as it exhibited in 1770, must have been frequently seen on former returns to perihelion; whereas no record of any such appearance was found.

To this Lexell replied, by showing that the elements of its orbit, derived from the observations made in 1770, were such, that at its previous aphelion, in 1767, the comet must have passed within a distance of the planet Jupiter fifty-eight times less than its distance from the sun; and that consequently it must then have sustained

an attraction from the great mass of that planet, more than three times more energetic than that of the sun; that consequently it was thrown out of the orbit in which it previously moved, into the elliptic orbit in which it actually moved in 1770; that its orbit previously to 1767 was, according to all probability, a parabola; and, in fine, that consequently moving in an elliptic orbit from 1767 to 1770, and having the periodicity consequent on such motion, it nevertheless moved only for the first time in its new orbit, and had never come within the sphere of the sun's attraction before this epoch.

Lexell further stated, that since the comet passed through its aphelion, which nearly intersected Jupiter's orbit, at intervals of somewhat above 5½ years, and it encountered the planet near that point in 1767, the period of the planet being somewhat above eleven years, the planet after a single revolution, and the comet after two revolutions, must necessarily again encounter each other in 1779; and, that since the orbit was such that the comet must in 1779 pass at a distance from Jupiter 500 times less than its distance from the sun, it must suffer from that planet an action 250 times greater than the sun's attraction, and that therefore it would in all probability be again thrown into a parabolic or hyperbolic path; and if so, that it would depart for ever from our system to visit other spheres of attraction. Lexell, therefore, anticipated the final disappearance of the comet, which actually took place.

In the interval between 1770 and 1779, the comet returned once to perihelion; but its position was such that it was above the horizon only during the day, and could not in the actual state of science be observed.

38. At this epoch analytical science had not yet supplied a definite solution of the problem of cometary disturbances. At a later period the question was resumed by Laplace who, in his celebrated work, the "Mécanique céleste," gave the general solution of the following problem:—

"The actual orbit of a comet being given, what was its orbit before, and what will be its orbit after being submitted to any given disturbing action of a planet near which it passes?"

39. Applying this to the particular case of Lexell's comet, and assuming as data the observations recorded in 1770, Laplace showed that, before sustaining the disturbing action of Jupiter in 1767, the comet must have moved in an ellipse of which the semi-axis major was 13·293, and consequently that its period, instead of being 5½ years, must have been 48½ years; and that the eccentricity of the orbit was such that its perihelion distance would be but very little less than the mean distance of Jupiter,

and that consequently it could never have been visible. It followed also that, after suffering the disturbing action of Jupiter in 1779, the comet passed into an elliptic orbit whose semi-axis major was 7·3, that its period was consequently twenty years, and that its eccentricity was such that its perihelion distance was more than twice the distance of Mars, and that in such an orbit it could not become visible.

40. This investigation was afterwards revised by M. Le Verrier,* which showed that the observations of 1770 were not sufficiently definite and accurate to justify conclusions so absolute. He has shown that the orbit of 1770 is subject to an uncertainty comprised between certain definite limits; that tracing the consequences of this to the positions of the comet in 1767 and 1779, these positions are subject to still wider limits of uncertainty. Thus he shows that, compatibly with the observations of 1770, the comet might in 1779 pass either considerably outside, or considerably inside Jupiter's orbit, or might, as it was supposed to have done, have passed actually within the orbits of his satellites. He deduces in fine the following general conclusions :—

1. That if the comet had passed within the orbits of the satellites, it must have fallen down upon the planet and coalesced with it; an incident which he thinks highly improbable, though not absolutely impossible.

2. The action of Jupiter may have thrown the comet into a parabolic or hyperbolic orbit, in which case it must have departed from our system altogether, never to return, except by the consequence of some disturbance produced in another sphere of attraction.

3. It may have been thrown into an elliptic orbit, having a great axis and long period, and so placed and formed that the comet could never become visible; a supposition within which comes the solution of Laplace.

4. It may have had merely its elliptic elements more or less modified by the action of the planet, without losing its character of short periodicity; a result which M. Le Verrier thinks the most probable, and which would render it possible that this comet may still be identified with some one of the many comets of short period, which the activity and sagacity of observers are every year discovering.

To facilitate such researches, M. Le Verrier has given a Table, including all the possible systems of elliptic elements of short period which the comet could have assumed, subject to the dis-

* See Mém. Acad. des Sciences, 1847, 1848.

turbing action of Jupiter in 1779, and taking the observations of 1770 within their possible limits of error.

He further demonstrates, that the orbit in which the comet moved antecedently to the disturbing action of Jupiter upon it in 1767, not only could not have been a parabola or hyperbola, but must have been an ellipse, whose major axis was considerably less than that which Laplace deduced from the insufficient observations of Messier. He shows that, before that epoch, the perihelion distance of the comet could not, under any possible supposition, have exceeded three times the earth's mean distance, and most probably was included between $1\frac{1}{2}$ and 2 times that distance; and that the semi-axis major of the orbit could not have exceeded $4\frac{1}{2}$ times the earth's mean distance, a magnitude 3 times less than that assigned to it by the calculations of Laplace.

41. It must not, however, be supposed that it is sufficient to compare the actual elements of each periodic comet thus discovered, with the elements given in the table of M. Le Verrier, and to infer the absence of identity from their discordance. Such an inference would only be rendered valid by showing, that in past ages, the comet in question had suffered no serious disturbing action by which the elements of its orbit could be considerably changed. To decide the question a much more laborious and difficult process must be encountered: a process from which the untiring spirit of M. Le Verrier has not shrunk. It is necessary, in fine, to the satisfactory and conclusive solution of such a problem, that the periodic comet in question should be traced back through all its previous revolutions up to 1779, that all the disturbances which it suffered from the planets which it encountered in that interval be calculated and ascertained, and that by such means the orbit which it must have had previous to such disturbances, in 1779, be determined. Such orbit would then be compared with the table of possible orbits of Lexell's comet, as given by M. Le Verrier; and if it were found to be identical with any of them, the identity of the comet in question with that of Lexell, would be inferred with the highest degree of probability; but if, on the other hand, such discrepancies were found to prevail as must exceed all supposable errors of observation or calculation, the diversity of the comets would follow.

42. M. Le Verrier has applied these principles to the comets of Faye, De Vico, and Brorsen; tracing back their histories during their unseen motions for three-quarters of a century, and ascertaining the effects of the disturbing actions which they must severally have sustained from revolution to revolution, until he

brought them to the epoch of 1779. On comparing the orbits thus determined with those of the table of possible orbits of Lexell's comet, he has shown that none of them can be identical with it, however strongly some of the elements of their present orbits may raise such a presumption.

43. The comet of De Vico having presented striking analogies with a comet which was observed by Tycho Brahe and Rothmann in 1585, and one observed by La Hire in 1678, M. Le Verrier has applied like principles to the investigation of these questions.

MM. Laugier and Mauvais observed that the elements of De Vico's comet presented such a resemblance to that of Tycho Brahe, as almost to decide the question of their identity. M. Le Verrier tracing back the comet of De Vico to 1585, has shown that its orbit at that epoch was so different from that of the comet of Tycho, as to be incompatible with any plausible inference of their identity.*

He has shown, however, by like reasoning, that there is a high degree of probability that the comet of De Vico is identical with that observed by La Hire in 1678.

44. M. Blainplan discovered a comet at Marseilles on the 28th November, 1819, which was observed at Milan until 25th January, 1820. The observations reduced and calculated by Prof. Encké gave an elliptic orbit with a period a little short of five years. Clausen conjectures that this comet may be identical with that of 1743. It has not been seen since 1820.

45. A comet was discovered by M. Pons on June 12th, 1819, which was observed until July 19th. Prof. Encké assigned to it an elliptic orbit, with a period of 5½ years.

46. A comet, discovered by Mr. Pigott at New York in 1783, was shown by Burckhardt to have an elliptic orbit, with a period of 5½ years.

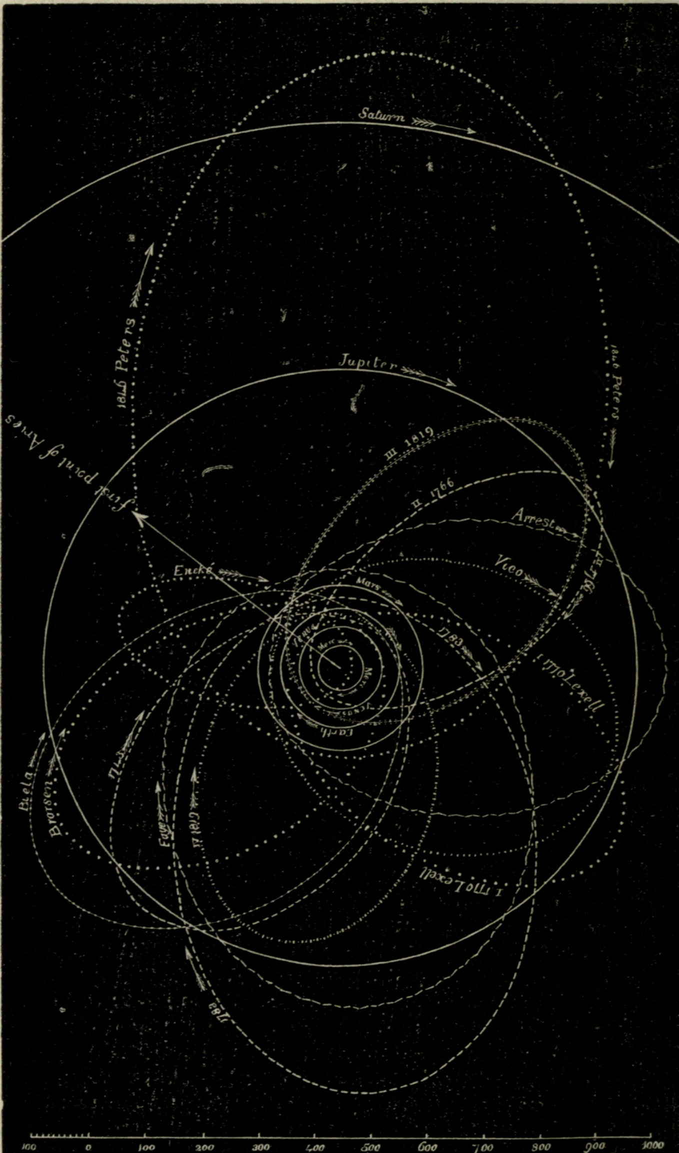
47. On the 26th June, 1846, a comet was discovered at Naples by M. Peters, which was subsequently observed at Rome by De Vico, and continued to be seen until 21st July. An elliptic orbit is assigned to this comet, with a period of from thirteen to sixteen years, some uncertainty attending the observations. The reappearance of this comet may be expected in 1859, 1860.

48. A synoptical Table, showing the elements of the elliptic comets above described, may be seen by a reference to my "Hand-Book of Astronomy."

49. In fig. 2 (page 172), the orbits of these thirteen comets brought to a common plane, are represented roughly but in their

* Mém. Acad. des Sciences, 1847.

Fig. 2.


Saturn
Jupiter
1846 Peters
First point of Aries
III 1819
II 1766
Arrest
Vico
Encke
Mars
1783
I 1770 Lexell
Earth
Venus
Mercur
Biela
Brorsen
Faye
1783
100
0
100
200
300
400
500
600
700
800
900
1000

proper proportions and relative positions, so as to exhibit to the eye their several ellipticities, and the relative directions of their axes.* All these bodies, without one exception, revolve in the common direction of the planets.

50. It is not alone, however, in the direction of their motions that the orbits of these bodies have an analogy to those of the planets. Their inclinations, with one exception, are within the limits of those of the planets. Their eccentricities, though incomparably greater than those of the planets, are, as will presently appear, incomparably less than those of all other comets yet discovered. Their mean distances and periods (with the exception of the last two in the Table just referred to) are within the limits of those of the planetoids.

The comparison of the numbers given in this Table with those in the Tables of the elements of other elliptic comets, and the comparison of the diagrams of their orbits with those of others, will show in a striking manner, to how great an extent the orbits of this group of comets possess the planetary character. Besides moving round the sun in the common direction, their inclinations, with a single exception, are within the limits of those of the planets. It is true that their eccentricities have an order of magnitude much greater; but on the other hand, it will be seen presently that they are incomparably less than the eccentricities of all other periodic comets yet discovered. Their mean distances and periods place them in direct analogy with the planetoids.

Moderate as are the eccentricities as compared with those of other comets, they are sufficiently great to impart a decided oval form to the orbits, and to produce considerable differences between the perihelion and aphelion distances, as will be apparent by inspecting the Table. It appears that while the perihelion of Encké's comet lies within the orbit of Mercury, its aphelion lies outside the orbit of the most remote of the planetoids, and not far within that of Jupiter. The perihelion of Biela's comet, in like manner, lies between the orbits of the earth and Venus, while its aphelion lies outside that of Jupiter. In the case of Faye's comet, the least eccentric of the group, the perihelion lies near the orbit of Mars, and the aphelion outside that of Jupiter.

It must be remembered that the elliptic form of these orbits has only been verified by observations on the successive returns to perihelion of the first five comets in the Table. The elliptic elements of the others may, so far as is at present known, have been effaced by disturbing causes.

* In the diagram, to prevent confusion, the orbits of the different comets are indicated by dotted or broken lines of different kinds.

The angular motions at the mean and extreme distances from the sun have been computed by the formulæ

$$a = \frac{1{,}296000}{365{\cdot}25 \times \mathrm{P}}, \qquad a' = a \times \frac{a^2}{d'^2}, \qquad a'' = \times a \frac{a^2}{d''^2}.$$

In which a represents the mean angular velocity, a' the greatest, and a'', the least; d' the perihelion, and d'' the aphelion distances. P is the periodic time of the comet, and a the mean distance. The same numbers which express these angular motions, also express in all cases the intensities of solar light and heat in the several positions of the comet; and also the apparent motion of the sun, as seen from the comet; and a comparison of these with the corresponding numbers related to any of the planets, will illustrate in a striking manner how different are the physical conditions by which these two classes of bodies are affected; and this will be more and more striking, when the other groups of comets have been noticed.

Taking the comet of Encké as an example, it appears that while its mean daily motion is 1076" or 18′, its motion in aphelion is only 5′, and in perihelion nearly 13°. Its motion in perihelion, the light and heat it receives from the sun, and the apparent motion of the sun as seen from it, are therefore severally more than 150 times greater in perihelion than in aphelion.

III.—ELLIPTIC COMETS, WHOSE MEAN DISTANCES ARE NEARLY EQUAL TO THAT OF URANUS.

51. It might be expected, that comets moving in elliptic orbits of small dimensions, and consequently having short periods, would have been the first in which the character of periodicity would be discovered. The comparative frequency of their returns to those positions near perihelion, where alone bodies of this class are visible from the earth, and the consequent possibility of verifying the fact of periodicity, by ascertaining the equality of the intervals between their successive returns to the same heliocentric position, to say nothing of the more distinctly elliptic form of the arcs of their orbits in which they can be immediately observed, would afford strong ground for such an expectation; nevertheless in this case, as has happened in so many others in the progress of physical knowledge, the actual results of observation and research have been directly contrary to such an anticipation; the most remarkable case of a comet of large orbit, long period, and rare returns, being the first, and those of small orbits, short

periods, and frequent returns, the last whose periodicity has been discovered.

52. It is evident that the idea of the possible existence of comets with periods shorter than those of the more remote planets, and orbits circumscribed within the limits of the solar system, never occurred to the mind either of Newton or any of his contemporaries or immediate successors.

In the third book of his PRINCIPIA, he calls comets a species of planets, revolving in elliptic orbits of a very oval form. But he continues, "I leave to be determined by others the transverse diameters and periods, by comparing comets which return *after long intervals of time* to the same orbits."

It is interesting to observe the avidity with which minds of a certain order snatch at such generalisations, even when but slenderly founded upon facts. These conjectures of Newton were soon after adopted by Voltaire: "Il y a quelque apparence," says he, in an essay on comets, "qu'on connaîtra un jour un certain nombre de ces autres planètes qui sous le nom de comêtes tournent comme nous autour du soleil, mais il ne faut pas espérer qu'on les connaissent toutes."

And again, elsewhere, on the same subject:—

> "Comêtes, que l'on craint à l'égal du tonnerre,
> Cessez d'épouvanter les peuples de la terre ;
> Dans une ellipse immense achevez votre cours,
> Remontez, descendez près de l'astre des jours."

53. Extraordinary as these conjectures must have appeared at the time, they were soon strictly realised. Halley undertook the labour of examining the circumstances attending all the comets previously recorded, with a view to discover whether any, and which of them, appeared to follow the same path. He found that a comet which had been observed by himself, by Newton, and their contemporaries in 1682, followed a path while visible, which coincided so nearly with those of comets which had been observed in 1607, and in 1531, as to render it extremely probable, that these objects were the same identical comet, revolving in an elliptic orbit of such dimensions, as to cause its return to perihelion at intervals of 75—76 years.

The comet of 1682 had been well observed by La Hire, Picard, Hevelius, and Flamstead, whose observations supplied all the data necessary to calculate its path while visible. That of 1607 had been observed by Kepler and Longomontanus; and that of 1531, by Pierre Apian at Ingolstadt, the observations in both cases being also sufficient for the determination of the path of the body, with all the accuracy necessary for its identification.

54. Of the identity of the paths while visible on each of these appearances Halley entertained no doubt, and announced to the world the discovery of the elliptic motion of comets, as the result of combined observation and calculation, and entitled to as much confidence as any other consequence of an established physical law; and predicted the re-appearance of this body, on its succeeding return to perihelion in 1758-9. He observed, however, that as in the interval between 1607 and 1682 the comet passed near Jupiter, its velocity must have been augmented, and consequently its period shortened by the action of that planet. This period, therefore, having been only seventy-five years, he inferred that the following period would probably be seventy-six years or upwards; and consequently that the comet ought not to be expected to appear until the end of 1758, or the beginning of 1759. It is impossible to imagine any quality of mind more enviable than that which, in the existing state of mathematical physics, could have led to such a prediction. The imperfect state of science rendered it impossible for Halley to offer to the world a demonstration of the event which he foretold. "He therefore," says M. de Pontecoulant, "could only announce these felicitous conceptions of a sagacious mind as mere intuitive perceptions, which must be received as uncertain by the world, however he might have felt them himself, until they could be verified by the process of a rigorous analysis."

Subsequent researches gave increased force to Halley's prediction; for it appeared from the ancient records of observers, that comets had been seen in 1456 and 1378, whose elements were identical with those of the comet of 1682.

Fig. 26.—Feb. 7, 1836.

Fig. 28.—Feb. 16, 1836.

HALLEY'S COMET DEPARTING FROM THE SUN IN 1836.

COMETS.

CHAPTER III.

Halley's prediction (continued). — 55. Great advance of mathematical and physical sciences between 1682 and 1759.—56. Exact path of the comet on its return, and time of its perihelion, calculated and predicted by Clairaut and Lalande. — 57. Remarkable anticipation of the discovery of Uranus.—58. Prediction of Halley and Clairaut fulfilled by reappearance of the comet in 1758-9.—59. Disturbing action of a planet on a comet explained.—60. Effect of the perturbing action of Jupiter and Saturn on Halley's comet between 1682 and 1758.—61. Calculations of its return in 1835-36.—62. Predictions fulfilled.—63. Elements of the orbit of Halley's comet.—64. Pons's comet of 1812.—65. Olbers's comet of 1815.—66. De Vico's comet of 1846.—67. Brorsen's comet of 1847.—68. Westphal's comet of 1852.—69. Data necessary to determine the motions of these six comets.—70. Diagram of their orbits.—71. Planetary characters are nearly effaced in these orbits.—IV. Elliptic Comets, whose mean distances exceed the limits of the Solar System: 72. Synopsis of twenty-one elliptic comets of great eccentricity and long period.—73. Plan of the form and relative magnitude of the orbits.—V. 74. Hyperbolic Comets: VI. 75. Parabolic Comets.—VII. Physical constitution of Comets: 76. Apparent form—head and tail.—77.

The appearance of the comet in 1456, was described by contemporary authorities to have been an object of "unheard-of magnitude;" it was accompanied by a tail of extraordinary length, which extended over sixty degrees (a third of the heavens), and continued to be seen during the whole of the month of June. The influence which was attributed to this appearance, renders it probable that in the record there exists more or less of exaggeration. It was considered as the celestial indication of the rapid success of Mohammed II., who had taken Constantinople, and struck terror into the whole Christian world. Pope Calixtus II. levelled the thunders of the Church against the enemies of his faith, terrestrial and celestial, and in the same bull exorcised the Turks and the comet; and in order that the memory of this manifestation of his power should be for ever preserved, he ordained that the bells of all the churches should be rung at midday—a custom which is preserved in those countries to our times. It must be admitted that, notwithstanding the terrors of the Church, the comet pursued its course with as much ease and security, as those with which Mohammed converted the church of St. Sophia into his principal mosque.

The extraordinary length and brilliancy which was ascribed to the tail upon this occasion, have led astronomers to investigate the circumstances under which its brightness and magnitude would be the greatest possible; and, upon tracing back the motion of the comet to the year 1456, it has been found that it was then actually under the circumstances of position with respect to the earth and sun most favourable to magnitude and splendour. So far, therefore, the results of astronomical calculation corroborate the records of history.

55. In the interval of three-quarters of a century which elapsed between the announcement of Halley's prediction and the date of its expected fulfilment, great advances were made in mathematical science; new and improved methods of investigation and calculation were invented; and, the theory of gravitation was pursued with extraordinary activity and success through its consequences in the mutual disturbances produced upon the motions of the planets and satellites, by the attraction of their masses one upon another. As the epoch of the expected return of the comet to its perihelion approached therefore, the scientific world resolved to divest, as far as possible, the prediction, of that vagueness which necessarily attended it owing to the imperfect state of science at the time it was made, and to calculate the exact effects

of those planets whose masses were sufficiently great, in accelerating or retarding its motion while passing near them.

56. This inquiry, which presented great mathematical difficulties and involved enormous arithmetical labour, was undertaken by Clairaut and Lalande: the former, a mathematician and natural philosopher, who had already applied with great success the principles of gravitation to the motions of the moon, undertook the purely analytical part of the investigation, which consisted in establishing certain general algebraical formulæ, by which the disturbing actions exerted by the planets on the comet were expressed; and Lalande, an eminent practical astronomer, undertook the labour of the arithmetical computations, in which he was assisted by a lady, Madame Lepaute, whose name has thus become celebrated in the annals of science.

When it is considered that the period of Halley's comet is about seventy-five years, and that for two successive periods, it was necessary to calculate every portion of its course separately in this way, some notion may be formed of the labour encountered by Lalande and Madame Lepaute. "During six months," says Lalande, "we calculated from morning till night, sometimes even at meals; the consequence of which was, that I contracted an illness which changed my constitution for the remainder of my life. The assistance rendered by Madame Lepaute was such, that without her we never could have dared to undertake this enormous labour, in which it was necessary to calculate the distance of each of the two planets, Jupiter and Saturn, from the comet, and their attraction upon that body, separately, for every successive degree, and for 150 years."

The name of Madame Lepaute does not appear in Clairaut's memoir; a suppression which Lalande attributes to the influence exercised by another lady to whom Clairaut was attached. Lalande, however, quotes letters of Clairaut, in which he speaks in terms of high admiration of "la savante calculatrice." The labours of this lady in the work of calculation (for she also assisted Lalande in constructing his "Ephemerides") at length so weakened her sight that she was compelled to desist. She died in 1788, while attending on her husband, who had become insane. See the article on comets, by Prof. de Morgan, in the "Companion to the British Almanac" for the year 1833.

These elaborate calculations being completed, Clairaut presented the result of their joint labours, in a memoir to the Academy of Sciences of Paris, in which he predicted the next arrival of the comet at perihelion, on the 18th of April, 1759; a date, however, which, before the re-appearance of the comet, he found reason to change to the 11th of April; and assigned the path which the

comet would follow while visible as determined by the following data :—

Inclination.	Longitude of node.	Longitude of perihelion.	Perihelion distance.	Direction.
17° 37′	53° 50′	303° 10′	0·58	retrograde.

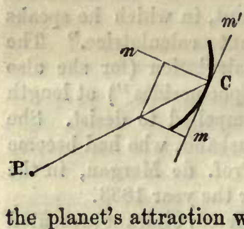
57. In announcing his prediction Clairaut stated, that the time assigned for the approaching perihelion might vary from the actual time to the extent of a month ; for that independently of any error either in the methods or process of calculation, the event might deviate more or less from its predicted occurrence, by reason of the attraction of *an undiscovered planet of our system revolving beyond the orbit of Saturn.* In twenty-two years after this time this conjecture was realised, by the discovery of the planet Uranus, by the late Sir William Herschel, revolving round the sun one thousand millions of miles beyond the orbit of Saturn !

58. The comet, in fine, appeared in December 1758, and followed the path predicted by Clairaut, which differed but little from that which it had pursued on former appearances. It passed through perihelion on the 13th of March, within twenty-two days of time, and within the limit of the possible errors assigned by Clairaut.

59. The general effects of a planet in accelerating or retarding the motion of a comet are easily explained, although the exact details of the disturbances are too complicated to admit of any exposition here.

Let P, fig. 3, represent the place of the disturbing planet, and C that of the comet. The attraction of the planet on the comet will then be a force directed from C towards P, and by the principle of the composition of forces is equivalent to two components, one C m in the direction of the comet's path, and the other C n perpendicular to that path. If the motion of the comet be directed from C towards m, it will be accelerated ; and if it be directed from C towards m', it will be retarded by that component of the planet's attraction which is directed from C to m. The other component C n being at right angles to the comet's motion, will have no direct effect either in accelerating or retarding it.

Fig. 3.

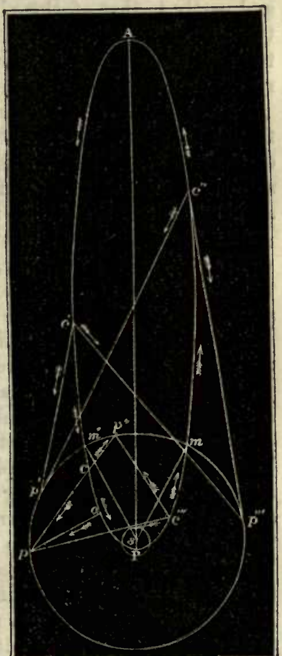


It appears, therefore, in general that, if the direction of the comet's motion C m make an acute angle with the line C P drawn to the planet, the planet's attraction will accelerate it; and if

its direction C m' make an obtuse angle with the line C P, it will retard it.

This being understood, the disturbing action of a planet such as Jupiter or Saturn on a comet such as Halley's may be easily comprehended. In fig. 4, the orbit of the comet is represented at A c P c'' in its proper proportions, A P being the major axis, P the place of perihelion, A that of aphelion, and S that of the focus in which the sun is placed. The small circle described round S represents in its proper proportions the orbit of the earth, whose distance is about twice that of the comet when the latter is at perihelion. The circle $p\ p'\ p''$ represents in its proper proportions the orbit of Jupiter which, for illustration, we shall consider as the disturbing planet.

Fig. 4.



It will be apparent on the mere inspection of the diagram, that lines drawn from the planet whatever be its place, to any point whatever of the comet's path between its aphelion A, and the point m' where it arrives at the orbit of the planet in approaching the sun, will make acute angles with the direction of the comet's motion; and that, consequently, the comet will be accelerated by the action of the planet. In like manner, it is apparent that lines drawn from the planet whatever be its place, to any point whatever of the comet's path between m and aphelion A, will make obtuse angles with the direction of the comet's motion; and, consequently, the comet will be retarded by the action of the planet, in departing from the sun, from m to A.

In that part of the comet's path which lies within the planet's orbit, the action of the planet alternately accelerates and retards it, according to their relative position. If the planet be at p, suppose $p\ o$ drawn so as to be at right angles to the path of the comet. Between m' and o the action of the planet at p will accelerate the comet, and after the comet passes o it will retard it. In like manner if the planet be at p'', it will first retard

the motion of the comet proceeding from m' through P towards A, and will continue to do so until the line of direction becomes perpendicular to that of the comet's motion, after which it will accelerate it.

It appears, therefore, that during the period of the comet, the disturbing action of the planet is subject to several changes of direction, owing partly to the change of position of the comet and partly to that of the planet; and the total effect of the disturbing action of the planet on the comet's period is found by taking the difference between the total amount of all the accelerating and all the retarding actions.

In the case of the planet Jupiter and Halley's comet, the former makes nearly seven complete revolutions in a single period of the comet; and consequently its disturbing action is not only subject to several changes of direction, but also to continual variation of intensity, owing to its change of distance from the comet.

Small as the arc m' P m of the comet's path is which is included within the orbit of Jupiter, the fraction of the period in which this arc is traversed by the comet is much smaller, as will be apparent by considering the application of the principle of equable areas * to this case. The time taken by the comet to move over the arc m' P m is in the same proportion to its entire period, as the area included between the arc m' P m and the lines m' S and m S is to the entire area of the ellipse A P.

To simplify the explanation the orbit of the comet has here been supposed to be in the plane of that of the disturbing planet. If it be not, the disturbing action will have another component at right angles to the plane of the comet's orbit, the effect of which will be a tendency to vary the inclination.

60. The result of the investigation by Clairaut showed, that the total effect of the disturbing action of Jupiter and Saturn on Halley's comet between its perihelions in 1682 and in 1759, was to increase its period by 618 days as compared with the time of its preceding revolution, of which increase, 100 days were due to the action of Saturn, and 518 to that of Jupiter.

Clairaut did not take into account the disturbing action of the earth, which was not altogether inconsiderable, and could not allow for those of the undiscovered planets, Uranus and Neptune. The effects of the action of the other planets, Mars, Venus, Mercury, and the planetoids, are in these cases insignificant.

61. In the interval of three quarters of a century which preceded the next re-appearance of this comet, science continued to progress, and instruments of observation and principles and

* See "Handbook of Astronomy," chap. xii. § 2599.

methods of investigation were still further improved; and, above all, the number of observers was greatly augmented. Before the epoch of its return in 1835, its motions, and the effects produced upon them by the disturbing action of the several planets, were computed by MM. Damoiseau, Pontecoulant, Rosenberger, and Lehmann, who severally predicted its arrival at perihelion:—

Damoiseau . . .	4th Nov. 1835.
Pontecoulant . . .	7th ,,
Rosenberger . . .	11th ,,
Lehmann . . .	26th ,,

62. These predictions were all published before July, 1835. The comet was seen at Rome on the 5th August, in a position within *one degree* of the place assigned to it for that day, in the ephemeris of M. Rosenberger. On the 20th August, it became visible to all observers, and pursued the course with very little deviation, which had been assigned to it in the ephemerides, arriving at its perihelion on the 16th Nov., being very nearly a mean between the four epochs assigned in the predictions.

After this, passing south of the equator, it was not visible in northern latitudes, but continued to be seen in the southern hemisphere until the 5th of May, 1836, when it finally disappeared, not again to return until the year 1911.

63. A synoptical Table of the elements of the orbit of this comet, deduced from the observations made on each of its seven successive returns to perihelion, between 1378 and 1835 inclusive, may be seen by a reference to the "Hand-Book of Astronomy."

It appears that the mean distance of this comet is about eighteen times that of the earth, and that it is consequently at a little less than the mean distance of Uranus. When in perihelion, its distance from the sun is about half the earth's distance, while its distance in aphelion is above thirty-five times the earth's distance, and therefore seventy times its perihelion distance.

64. On the 20th of July, 1812, a comet was discovered by M. Pons, whose orbit was calculated by Professor Encké, and was found to be an ellipse of such dimensions as to give a period of $75\frac{1}{2}$ years, equal to that of Halley's comet.

65. On the 6th of March, 1815, Dr. Olbers discovered at Bremen, a comet whose orbit, calculated by Professor Bessel, proved to be an ellipse, with a period of 74 years. The next perihelion passage of this comet is predicted for the 9th of February, 1887.

66. On the 28th of February, 1846, M. de Vico discovered a comet at Rome, whose orbit, calculated by MM. van Deinse and Pierce, appears to be an ellipse, with a period of 72-73 years.

67. A comet was discovered by M. Brorsen at Altona, on the 20th of July, 1847; the orbit of which, calculated by M. d'Arrest, appears to be an ellipse, with a period of 75 years.

68. On the 27th of June, 1852, a comet was discovered by M. Westphal at Gottingen, and was soon afterwards observed by M. Peters at Constantinople. The calculation of its orbit proves it to be an ellipse, with a period of about 70 years.

69. A synoptical Table, presenting the data necessary to determine the motions of these six comets, may be seen by a reference to the "Hand-Book of Astronomy."

70. In fig. 5 (p. 145), is presented a plan of the orbits, brought upon a common plane, and drawn according to the scale indicated. This figure shows, in a manner sufficiently exact for the purposes of illustration, the relative magnitudes and the forms of the six orbits, as well as the directions of their several axes with relation to that of the first point of Aries.

71. By comparing the elements given in the table referred to above, and the forms and magnitudes of the orbits shown in the diagram, with those of the first group of elliptic comets given in Table III, "Hand-Book of Astronomy," chap. XVIII, and drawn in fig. 2 (p. 172), it will be perceived that the planetary characteristics noticed in the latter group, are nearly effaced. Five of the six comets composing the second group, revolve in the common direction of the planets, and this is the only planetary character observable among them. The inclinations, no longer limited to those of the planetary orbits, range from 18° to 74°. The eccentricities are all so extreme, that the arc of the orbit near perihelion approximates closely to the parabolic form, and the most remarkable body of the group, the comet of Halley, revolves in a direction contrary to the common motion of the planets.

But it is more than all in the elongated oval form of their orbits, that this group of comets differs, not only from the planets, but from the first group. While their perihelia are at distances from the sun, between those of Mars and Mercury, their aphelia are from two to five hundred millions of miles outside the orbit of Neptune. Thus, the comet of Halley, for example, in perihelion, is at a distance from the sun less than that of Venus; but at its aphelion, its distance exceeds that of Neptune by a space greater than Jupiter's distance from the sun. The mean angular motion of this comet is nearly the same as that of Uranus; but its angular motion in perihelion is three times that of Mercury;

while its angular motion in aphelion is little more than half that of Neptune.

The corresponding variations of solar light and heat, and of the apparent magnitude and motion of the sun as seen from the comet, may be easily inferred.

IV.—ELLIPTIC COMETS WHOSE MEAN DISTANCES EXCEED THE LIMITS OF THE SOLAR SYSTEM.

72. Although the periodicity of this class of comets has not yet in any instance been certainly established by observations made upon their successive returns to perihelion, the observations made upon them during a single perihelion passage indicate an arc of their orbit, which exhibits the elliptic form so unequivocally, as to supply computers and mathematicians with the data necessary to obtain, with more or less approximation, the value of the eccentricity, which, combined with the perihelion distance, gives the form and magnitude of the comet's orbit.

By calculations conducted in this manner, and applied to the observations made on various comets which have appeared since the latter part of the seventeenth century, the elliptic orbits of twenty-one of these bodies have been computed, and are given in the order of the dates of their perihelion passages in a table which will be found in my "Hand-Book of Astronomy."

Of this group the least eccentric is No. 15, which passed its perihelion in 1840. This comet was discovered at Berlin by M. Bremiker, and its orbit was calculated by Götze, and proved to be an ellipse, having the elements given in the table, subject to no greater uncertainty than $\frac{1}{64}$th of the value assigned to the mean distance. The eccentricity, and consequently the form of the orbit, is similar to that of Halley, but the major axis is $2\frac{2}{3}$ times, and the period nearly five times greater. Its perihelion distance is equal to that of Mars, and its aphelion distance more than three times that of Neptune.

No. 6, which passed its perihelion in 1793, has an orbit, according to the calculations of D'Arrest, nearly similar both in form and magnitude, as will be seen by comparing the numbers given in the table. More uncertainty, however, attends the estimation of these elements.

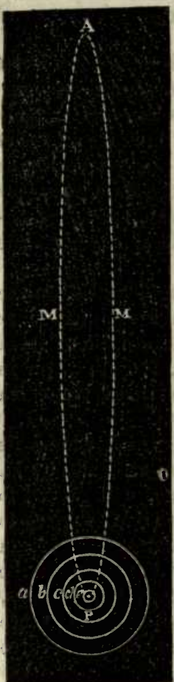
The comets which approached nearest to the sun were the great comets of 1680 and 1843, Nos. 1 and 16 in the table, both memorable for their extraordinary magnitude and splendour.

The elements of that of 1680, given in the table, are those

which have resulted from the calculations of Professor Encké, based on all the observations of the comet which have been recorded. The elements of the great comet of 1843 have resulted from the computations of Mr. Hubbard. Both are subject to considerable uncertainty, and must be accepted only as the best approximations that can be obtained.

What is not subject, however, to the same uncertainty, is the extraordinary proximity of these bodies to the sun at their respective perihelia. The perihelion distance of the comet of 1680 was about 576000 miles, and that of 1843, 538000 miles. Now the semidiameter of the sun being 441000 miles, it follows that the distance of the centres of those comets respectively from the surface of the sun at perihelion must have been only 235000 and 97000; so that if the semidiameter of the nebulous envelope of either of them exceeded this distance, they must have actually grazed the sun.

Fig. 6.



The velocity of the orbital motion of these bodies in perihelion appears by the table to be such, that the comet of 1680 would have revolved round the sun in a minute, and that of 1843 in a little less than two minutes, if they retained the same angular motion undiminished.

The distance to which the comet of 1680 recedes in its aphelion is $28\frac{1}{2}$ times greater than that of Neptune. The apparent diameter of the sun seen from that distance would be 2″, and the intensity of its light and heat would be 730000 times less than at the earth; while their intensity at the perihelion distance would be 26000 times greater, so that the light and heat received by the comet in its aphelion would be $26000 \times 730000 = 18980$ million times less than in perihelion.

The greatest aphelion distances in the table are those of Nos. 5, 13, and 17, the comets of 1780, 1830, and 1844, amounting to from 100 to 140 times the distance of Neptune; the eccentricities differing from unity by less than $\frac{1}{1000}$. These orbits, though strictly the results of calculation, must be regarded as subject to considerable uncertainty.

73. To convey an idea of the form of the orbits of the comets of this group, and of the proportion which their magnitude bears to the dimensions of the solar system, we have drawn in

fig. 6, an ellipse, which may be considered as representing the form of the orbits of the comets Nos. 15, 6, 9, 12, and 1, of Table VI in the "Handbook of Astronomy."

If the ellipse represent the orbit of the comet No. 15, the circle *a* will represent on the same scale the orbit of Neptune.

If the ellipse represent the orbit of the comet No. 6, the circle *b* will represent the orbit of Neptune.

If the ellipse represent the orbit of No. 9, the circle *c* will represent the orbit of Neptune.

If the ellipse represent the orbit of No. 12, the circle *d* will represent the orbit of Neptune.

If the ellipse represent the orbit of No. 1, the circle *e* will represent the orbit of Neptune.

V.—HYPERBOLIC COMETS.

74. In a Table in the "Hand-Book of Astronomy" are given the elements of seven comets which appear by the results of calculations made upon the observations to have passed through the system in hyperbolic orbits.

VI.—PARABOLIC COMETS.

75. Of all the remaining number of comets which have been seen in the heavens and recorded in history, one hundred and sixty-one have been observed with sufficient precision to enable astronomers to determine, with more or less approximation, their parabolic orbits. A table giving the elements of these, with the dates of their appearance, will be found in the eighteenth chapter of the "Handbook of Astronomy."

VII.—PHYSICAL CONSTITUTION OF COMETS.

76. Comets in general, and more especially those which are visible without a telescope, present the appearance of a roundish mass of illuminated vapour or nebulous matter, to which is often, though not always, attached a train more or less extensive, composed of matter having a like appearance. The former is called the HEAD, and the latter the TAIL, of the comet.

77. The illumination of the head is not generally uniform. Sometimes a bright central spot is seen in the nebulous matter which forms it. This is called the NUCLEUS.

The nucleus sometimes appears as a bright stellar point, and

sometimes presents the appearance of a planetary disc seen through a nebulous haze. In general, however, on examining the object with high optical power, these appearances are changed, and the object seems to be a mere mass of illuminated vapour from its borders to its centre.

78. When a nucleus is apparent, or supposed to be so, the nebulous haze which surrounds it and forms the exterior part of the head is called the *coma*.

79. These designations are taken from the Greek word κομή (komé) hair, the nebulous matter composing the coma and tail being supposed to resemble hair, and the object being therefore called κομήτης (kometes), a hairy star.

80. As the brightness of the coma gradually fades away towards the edges, it is impossible to determine with any great degree of precision its real dimensions. These, however, are obviously subject to enormous variation, not only in different comets compared one with another, but even in the same comet during the interval of a single perihelion passage. The greatest of those which have been submitted to micrometrical measurement was the great comet of 1811, the diameter of the head of which was found to be not less than $1\frac{1}{8}$ millions of miles, which would give a volume greater than that of the sun in the ratio of about 2 to 1. The diameter of the head of Halley's comet when departing from the sun, in 1836, at one time measured 357000 miles, giving a volume more than sixty times that of Jupiter. These are, however, the greatest dimensions which have been observed in this class of objects, the diameter rarely exceeding 200000 miles, and being generally less than 100000.

81. Attempts have been made where nuclei were perceivable, to estimate their magnitude, and diameters have been assigned to them, varying from 100 to 5000 miles. For the reasons, however, already explained, these results must be regarded as very doubtful.

Those who deny the existence of solid matter within the coma, maintain that even the most brilliant and conspicuous of those bodies, and those which have presented the strongest resemblance to planets, are more or less transparent. It might be supposed that a fact so simple as this, in this age of astronomical activity, could not remain doubtful; but it must be considered, that the combination of circumstances which alone would test such a question, is of rare occurrence. It would be necessary that the centre of the head of the comet, although very small, should pass critically over a star, in order to ascertain whether such star is visible through it. With comets having extensive comæ without nuclei, this has sometimes occurred; but we have not had such

satisfactory examples in the more rare instances of those which have distinct nuclei.

In the absence of a more decisive test of the occultation of a star by the nucleus, it has been maintained that the existence of a solid nucleus may be fairly inferred from the great splendour which has attended the appearance of some comets. A mere mass of vapour could not, it is contended, reflect such brilliant light. The following are the examples adduced by Arago:—

"In the year 43 before Christ, a comet appeared which was said to be visible to the naked eye by daylight. It was the comet which the Romans considered to be the soul of Cæsar transferred to the heavens after his assassination.

"In the year 1402 two remarkable comets were recorded. The first was so brilliant that the light of the sun at noon, at the end of March, did not prevent its nucleus, or even its tail, from being seen. The second appeared in the month of June, and was visible also for a considerable time before sunset.

"In the year 1532, the people of Milan were alarmed by the appearance of a star which was visible in the broad daylight. At that time Venus was not in a position to be visible, and consequently it is inferred that this star must have been a comet.

"The comet of 1577 was discovered on the 13th of November by Tycho Brahe, from his observatory on the isle of Huene, in the Sound, before sunset.

"On the 1st of February, 1744, Chizeaux observed a comet more brilliant than the brightest star in the heavens, which soon became equal in splendour to Jupiter, and in the beginning of March it was visible in the presence of the sun. By selecting a proper position for observation, on the 1st of March it was seen at one o'clock in the afternoon without a telescope."

Such is the amount of evidence which observation has supplied respecting the existence of a solid nucleus. The most that can be said of it is, that it presents a plausible argument, giving some probability, but no positive certainty, that comets have visited our system which have solid nuclei, but, meanwhile, this can only be maintained with respect to a few: most of those which have been seen, and all to which very accurate observations have been directed, have afforded evidence of being mere masses of semi-transparent matter.

82. Although by far the great majority of comets are not attended by tails, yet that appendage, in the popular mind, is more inseparable from the idea of a comet than any other attribute of these bodies. This proceeds from its singular and striking appearance, and from the fact that most comets visible to the naked eye have had tails. In the year 1531, on the occasion of

one of the visits of Halley's comet to the solar system, Pierre Apian observed that the comet generally presented its tail in the direction opposite to that of the sun. This principle was hastily generalised, and is even at present too generally adopted. It is true that in most cases the tail extends itself from that part of the comet which is most remote from the sun; but its direction rarely corresponds with the direction which the shadow of the comet would take. Sometimes it has happened that the tail forms with a line drawn to the sun a considerable angle, and cases have occurred when it was actually at right angles to it.

Another character which has been observed to attach to the tails of comets, which, however, is not invariable, is, that they incline constantly toward the region last quitted by the comet, as if in its progress through space it were subject to the action of some resisting medium, so that the nebulous matter with which it is invested, suffering more resistance than the solid nucleus, remains behind it and forms the tail.

The tail sometimes appears to have a curved form. That of the comet of 1744 formed almost a quadrant. It is supposed that the convexity of the curve, if it exists, is turned in the direction from which the comet moves. It is proper to state, however, that these circumstances regarding the tail have not been clearly and satisfactorily ascertained.

The tails of comets are not of uniform breadth or diameter; they appear to diverge from the comet, enlarging in breadth and diminishing in brightness as their distance from the comet increases. The middle of the tail usually presents a dark stripe, which divides it longitudinally into two distinct parts. It was long supposed that this dark stripe was the shadow of the body of the comet, and this explanation might be accepted if the tail was always turned from the sun; but we find the dark stripe equally exists when the tail, being turned sideways, is exposed to the effect of the sun's light.

This appearance is usually explained by the supposition that the tail is a hollow, conical shell of vapour, the external surface of which possesses a certain thickness. When we view it, we look through a considerable thickness of vapour at the edges, and through a comparatively small quantity at the middle. Thus upon the supposition of a hollow cone, the greatest brightness would appear at the sides, and the existence of a dark space in the middle would be perfectly accounted for.

The tails of comets are not always single; some have appeared at different times with several separate tails. The comet of 1744, which appeared on the 7th or 8th of March, had six tails, each about 4° in breadth, and from 30° to 44° in length. Their

sides were well defined and tolerably bright, and the spaces between them were as dark as the other parts of the heavens.

The tails of comets have frequently appeared, not only of immense real length, but extending over considerable spaces of the heavens. It will be easily understood that the apparent length depends conjointly upon the real length of the tail, and the position in which it is presented to the eye. If the line of vision be at right angles to it, its length will appear as great as it can do at its existing distance; if it be oblique to the eye, it will be foreshortened, more or less, according to the angle of obliquity. The real length of the tail is easily calculated when the apparent length is observed and the angle of obliquity known.

In respect of magnitude, the tails are unquestionably the most stupendous objects which the discoveries of the astronomer have ever presented to human contemplation.

The following are the results of the observation and measurement of a few of the more remarkable.

Table.	No.	Date of Appearance.	Greatest observed Length of Tail.
			miles.
VIII	148	1847	5000000
—	73	1744	19000000
VI	4	1769	40000000
VIII	46	1618	50000000
VI	1	1680	100000000
—	8	1811	100000000
—	9	1811	130000000
—	16	1843	200000000

The magnitude of these prodigious appendages is even less amazing than the brief period in which they sometime emanate from the head. The tail of the comet of 1843, long enough to stretch from the sun to the planetoids, was formed in less than twenty days.

83. The masses of comets, like those of the planets, would be ascertained if the reciprocal effects of their gravitation and those of any known bodies in the system could be observed. But although the disturbing action of the planets on these bodies is conspicuous, and its effects have been calculated and observed, not the slightest effect of the same kind has ever been ascertained to be produced by them, even upon the smallest bodies in the system, and those to which comets have approached most nearly.

In fine, notwithstanding the enormous number of comets,

observed and unobserved, which constantly traverse the solar system in all conceivable directions; notwithstanding the permanent revolution of the periodic comets, whose presence and orbits have been ascertained; notwithstanding the frequent visits of comets, which so thoroughly penetrate the system as almost to touch the surface of the sun at their perihelion, the motions of the various bodies of the system, great and small, planets major and minor, planetoids and satellites, go on precisely as if no such bodies as the comets approached their neighbourhood. Not the smallest effects of the attraction of such visitors are discoverable.

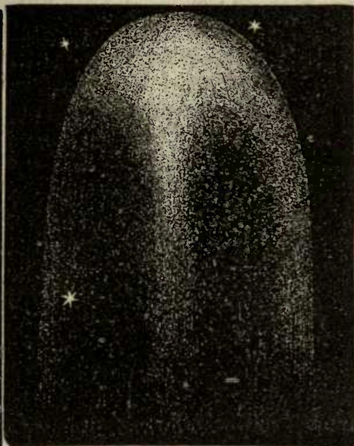
Now since, on the other hand, the disturbing effects of the planets upon the comets are strikingly manifest, and since the comets move in elliptic, parabolic, or hyperbolic orbits, of which the sun is the common focus, it is demonstrated that these bodies are composed of ponderable matter, which is subject to all the consequences of the law of gravitation. It cannot, therefore, be doubted that the comets do produce a disturbing action on the planets, although its effects are inappreciable even by the most exact observation. Since, then, the disturbances mutually produced are in the proportion of the disturbing masses, it follows that the masses of the comets must be smaller beyond all calculation than the masses even of the smallest bodies among the planets primary or secondary.

The volumes of comets in general exceed those of the planets in a proportion nearly as great as that by which the masses of the planets exceed those of the comets. The consequence obviously resulting from this, is that the density of comets is incalculably small.

Their densities in general are probably thousands of times less than that of the atmosphere in the stratum next the surface of the Earth.

Fig. 27.—February 10, 1836.

Fig. 29.—February 23, 1836.



HALLEY'S COMET DEPARTING FROM THE SUN IN 1836.

COMETS.

CHAPTER IV.

84. Light of comets.—85. Enlargement of magnitude on departing from the sun.—86. Professor Struve's drawings of Encké's comet.—87. Remarkable physical phenomena manifested by Halley's comet.—88. Struve's drawings of the comet approaching the sun in 1835.—89. Its appearance on the 29th of Sept.—90. Appearance on Oct. 3.—91. Appearance on Oct. 6.—92. Appearance on Oct. 9.—93. Appearance on Oct. 10.—94. Appearance on Oct. 12.—95. Appearance on Oct. 14.—96. Appearance on Oct. 29.—97. Appearance on Nov. 5.—98. Sir J. Herschel's deductions from these phenomena.—99. Appearance of the comet after perihelion.—100. Observations and drawings of MM. Maclear and Smith.—101. Appearance on Jan. 24.—102. Appearance on Jan. 25.—103. Appearance on Jan. 26.—104. Appearance on Jan. 27.—105. Appearance on Jan. 28.—106. Appearance on Jan. 30.—107. Appearance on Feb. 1.—108. Appearance on Feb. 7.—109. Appearance on Feb. 10.—110. Appearance on Feb. 16 and 23.—111. Number of comets.—112. Duration of the appearance of comets.—113. Near approach of comets to the earth.

84. THAT planets are not self-luminous, but receive their light from the sun, is proved by their phases, and by the shadows of

their satellites, which are projected upon them, when the latter are interposed between them and the sun. These tests are inapplicable to comets. They exhibit no phases, and are attended by no bodies to intercept the sun's light. But, unless it could be shown that a comet is a solid mass, impenetrable to the solar rays, the non-existence of phases is not a proof that the body does not receive its light from the sun.

A mere mass of cloud or vapour, though not self-luminous, but rendered visible by borrowed light, would still exhibit no effect of this kind: its imperfect opacity would allow the solar light to affect its constituent parts throughout its entire depth—so that, like a thin fleecy cloud, it would appear not superficially illuminated, but receiving and reflecting light through all its dimensions. With respect to comets, therefore, the doubt which has existed is, whether the light which proceeds from them, and by which they become visible, is a light of their own, or is the light of the sun shining upon them, and reflected to our eyes like light from a cloud. Among several tests which have been proposed to decide this question, one suggested by Arago merits attention.

It has been already shown in our Tract on "the Eye" (43), that the apparent brightness of a visible object is the same at all distances, supposing its real brightness to remain unchanged. Now if comets shone with their proper light, and not by light received from the sun, their apparent brightness would not decrease as they would recede from the sun, and they would cease to be visible, not because of the faintness of their light, but because of the smallness of their apparent magnitude. Now the contrary is found to be the case. As the comet retires from the sun its apparent brightness rapidly decreases, and it ceases to be visible from the mere faintness of its light, while it still subtends a considerable visual angle.

85. It will doubtless excite surprise, that the dimensions of a comet should be enlarged as it recedes from the source of heat. It has been often observed in astronomical inquiries, that the effects, which at first view seem most improbable, are nevertheless those which frequently prove to be true; and so it is in this case. It was long believed that comets enlarged as they approached the sun; and this supposed effect was naturally and probably ascribed to the heat of the sun expanding their dimensions. But more recent and exact observations have shown the very reverse to be the fact. Comets increase their apparent volume as they recede from the sun; and this is a law to which there appears to be no well-ascertained exception. This singular and unexpected phenomenon has been attempted to be accounted

for in several ways. Valz ascribed it to the pressure of the solar atmosphere acting upon the comet; that atmosphere being more dense near the sun, compresses the comet and diminishes its dimensions; and, at a greater distance, being relieved from this coercion, the body swells to its natural bulk. A very ingenious train of reasoning was produced in support of this theory. The density of the solar atmosphere and the elasticity of the comet, being assumed to be such as they might naturally be supposed, the variations of the comet's bulk are deduced by strict reasoning, and show a surprising coincidence with the observed change in the dimensions. But this hypothesis is tainted by a fatal error. It proceeds upon the supposition that the comet, on the one hand, is formed of an elastic gas or vapour; and, on the other, that it is impervious to the solar atmosphere through which it moves. To establish the theory, it would be necessary to suppose that the elastic fluid composing the comet should be surrounded by a *nappe* or envelope as elastic as the fluid composing the comet, and yet wholly impenetrable by the solar atmosphere.

Several ingenious hypotheses * have been proposed and successively rejected for explaining this phenomenon, but it seems now agreed to ascribe it to the action of the varying temperature to which the vapour which composes the nebulous envelope is exposed. As the comet approaches the sun, this vapour is converted by intense heat into a pure, transparent, and therefore invisible elastic fluid. As it recedes from the sun, the temperature decreasing, it is partially and gradually condensed, and assumes the form of a semitransparent visible cloud, as steam does escaping from the valve of a steam boiler. It becomes more and more voluminous as the distance from the source of heat, and therefore the extent of condensation, is augmented.

86. Professor Struve made a series of observations on the comet of Encké, at the period of its reappearance in 1828, and by the aid of the great Dorpat telescope, made the drawings figs. 7 and 8.

Fig. 7 represents the comet as it appeared on the 7th November, the diameter $a\ b$ measuring 18′. The brightest part of the comet extended from k to l, and was consequently eccentric to it, the distance of the centre of brightness from the centre of magnitude being k K. Between the 7th and the 30th November, the magnitude of the comet decreased from that represented in fig. 7, to that represented in fig. 8; but the

* For several of these, see Sir J. Herschel's memoir, "Proceedings of Astronomical Society," vol. vi. p. 104.

apparent brightness was so much increased, that at the latter date it was visible to the naked eye as a star of the 6th magnitude. The apparent diameter was then reduced to 9′.

On November 7th a star of the 11th magnitude was seen through the comet, so near the centre of brightness that it was for a moment mistaken for a nucleus. The brightness of the star was not in the least perceptible degree dimmed by the mass of cometary matter through which its light passed.

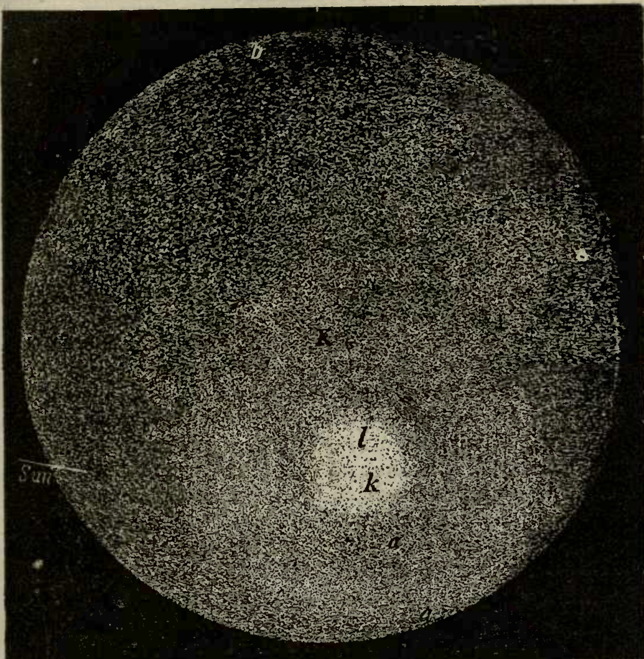
It was evident that the increase of the brightness of the comet on the 30th November, must be ascribed to the contraction, and consequent condensation, of the nebulous matter composing it in receding from the sun, for its distance from the earth on the 7th November, when it subtended an angle of 18′, was 0·515 (the earth's mean distance from the sun being =1); while its distance on the 30th, when it subtended an angle of 9′, was only 0·477. Its cubical dimensions must, therefore, have been diminished, and the density of the matter composing it augmented in more than eight-fold proportion.

87. The expectation so generally entertained, that, on the occasion of its return to perihelion in 1835, this comet would afford observers occasion for obtaining new data, for the foundation of some satisfactory views respecting the physical constitution of the class of which it is so striking an example, was not disappointed. It no sooner reappeared than phenomena began to be manifested, preceding and accompanying the gradual formation of the tail, the observation of which has been most justly regarded as forming a memorable epoch in astronomical history.

Happily, these strange and important appearances were observed with the greatest zeal, and delineated with the most elaborate and scrupulous fidelity by several eminent astronomers in both hemispheres. MM. Bessel at Konigsburg, Schwabe at Dessau, and Struve at Pultowa, and Sir J. Herschel and Mr. Maclear at the Cape of Good Hope, have severally published their observations, accompanied by numerous drawings, exhibiting the successive transformations presented under the physical influence of varying temperature, in its approach to and departure from the sun.

The comet first became visible as a small round nebula, without a tail, and having a bright point more intensely luminous than the rest eccentrically placed within it. On the 2nd October, the tail began to be formed, and, increasing rapidly, acquired a length of about 5° on the 5th; on the 20th it attained its greatest length, which was 20°. It began after that day to decrease, and its diminution was so rapid, that on the 29th it was reduced to 3°,

Fig. 7.—Encké's Comet, 1828, approaching the Sun; as it appeared 7th Nov., 1828. (Telescopic drawing by Struve.)



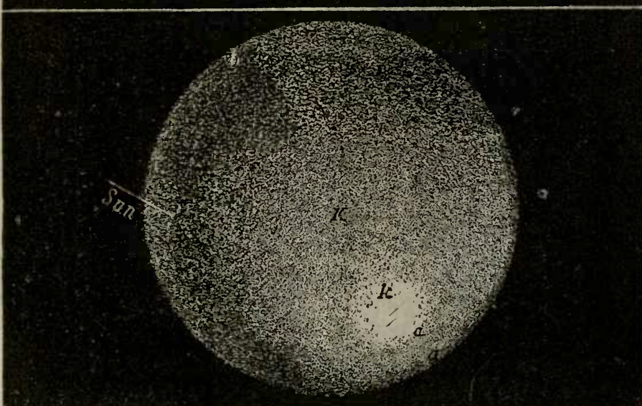


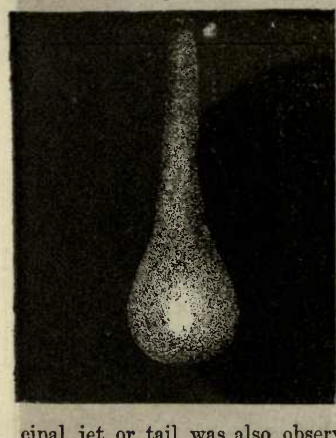
Fig. 8.—The same as it appeared 30th November, 1828.

and on the 5th of November, to $2\frac{1}{2}°$. The comet was observed on the day of its perihelion by M. Struve, at the Observatory of Pultowa, when no tail whatever was apparent.

The circumstances which accompanied the increase of the tail from 2nd October, until its disappearance, were extremely remarkable, and were observed with scrupulous precision, simultaneously by Bessel at Kouigsburg, by Struve at Pultowa, and by Schwabe at Dessau, all of whom made drawings from time to time, delineating the successive changes which it underwent.

On the 2nd, the commencement of the formation of the tail took place, by the appearance of a violent ejection of nebulous matter from that part of the comet which was presented towards the sun. This ejection was, however, neither uniform nor continuous. Like the fiery matter issuing from the crater of a volcano, it was thrown out at intervals. After the ejection, which was conspicuous, according to Bessel, on the 2nd, it ceased, and no efflux was observed for several days. About the 8th, however, it recommenced more violently than before, and assumed a new form. At this time Schwabe noticed an appearance which he denominates a "second tail," presented in a direction opposed to that of the original tail, and, therefore, towards the sun. This appearance seems, however, to be regarded by Bessel merely as the renewed ejection of nebulous matter which was afterwards turned back from the sun, as smoke would be by a current of air blowing from the sun in the direction of the original tail.

Fig. 9.—Sept. 29, 1835.

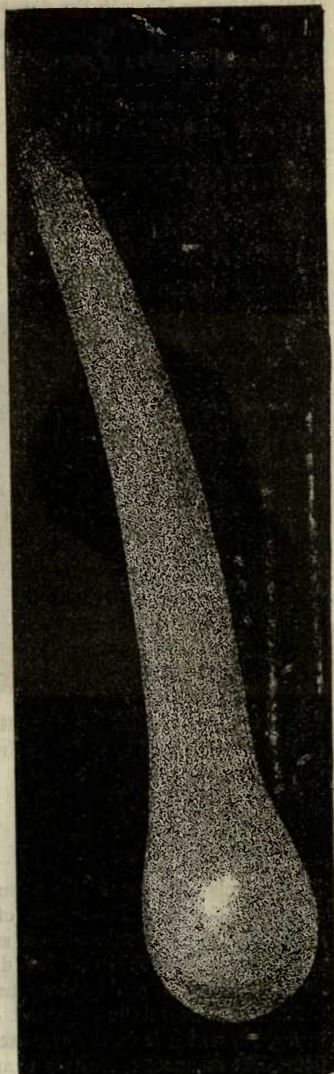


From the 8th to the 22nd, the form, position, and brightness of the nebulous emanations underwent various and irregular changes, the last alternately increasing and decreasing.

At one time two, at another three, nebulous emanations were observed to issue in divergent directions. These directions were continually varying, as well as their comparative brightness. Sometimes they would assume a swallow-tailed form, resembling the flame issuing from a fan gas-burner. The principal jet or tail was also observed to oscillate on the one side and the other of a line drawn from the sun through the centre

of the head of the comet, exactly as a compass needle oscillates between the one and the other side of the magnetic meridian. This oscillation was so rapid, that the direction of the jets was visibly changed from hour to hour. The brightness of the matter composing them, being most intense at the point at which it seemed to be ejected from the nucleus, faded away as it expanded into the coma, curving backwards, in the direction of the principal tail, like steam or smoke before the wind.

Fig. 10.—Oct. 3, 1835.

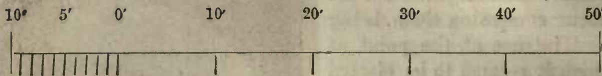


88. These curious phenomena will, however, be more clearly conceived by the aid of the admirable drawings of M. Struve, which we have reproduced with all practicable fidelity, in figs. 9, 10, 11, 12, 13, 14, 15, 16, 17, and 18. These drawings were executed by M. Kruger, an eminent artist, from the immediate observation of the appearances of the comet with the great Fraunhoffer telescope, at the Pultowa Observatory. The sketches of the artist were corrected by the astronomer, and only adopted definitively after repeated comparisons with the object. The original drawings are preserved in the library of the observatory.

89. Fig. 9 (page 198) represents the appearance of the comet on the 29th September. The tail was difficult to be recognised, appearing to be composed of very feeble nebulous matter. The nucleus passed

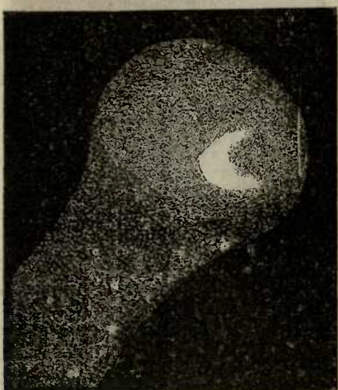
almost centrically over a star of the tenth magnitude, without in the slightest degree affecting its apparent brightness. The star was distinctly seen through the densest part of the comet. Another transit of a star took place with a like result.

Annexed is the scale according to which this drawing has been made.

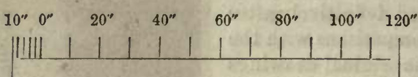


90. The comet changed not only its magnitude and form, but also its position, after September 29. On that day the direction of the tail was that of the parallel of declination through the head. On October 3rd it was inclined from that parallel towards the north at a small angle, and, instead of being straight, was curved, as shown in fig. 10 (page 199). The diameter of the head was increased in the ratio of 2 to 3, and the length of the tail in the ratio of nearly 1 to 3.

Fig. 11.—Oct. 8, 1835.



91. On the 5th, 6th, and 7th the comet underwent several changes: the nucleus became more conspicuous. On the 6th, a fan-formed flame issued from it, which disappeared on the 7th, and re-appeared on the 8th with increased splendour, as represented in fig. 11, which is drawn on the subjoined scale:



The nucleus appeared like a burning coal of oblong form, and yellowish colour. The extent of the flame-like emanation was about 30″. The feeble nebula surrounding the nuclei extended much beyond the limits of the drawing, but, being overpowered by the moonlight, could not be measured.

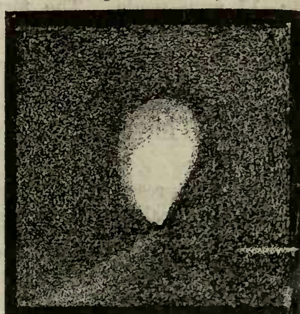
92. The comet as it appeared on the following night is shown in fig. 12, which is on the same scale as fig. 11. The nucleus and flame-like emanation entirely changed their form and magnitude

since the preceding night. The tail (not included in the drawing) measured very nearly 2°. The flame consisted of two parts, one resembling that seen on the 8th, and the other issuing like the jet from a blow-pipe in a direction at right angles to it. The figure represents the nucleus and flame as they appeared at 21^h sidereal time, with a magnifying power of 254.

Fig. 12.—Oct. 9, 1835.

93. The appearance of the following night is shown on the same scale in fig. 13. The tail, which still measured nearly 2°, was now much brighter, being visible to the naked eye, notwithstanding strong moonlight. The coma was evidently broader than the tail. The flaming nucleus is represented in the drawing as it appeared under a magnifying power of 86, with a field of 18′ diameter, the entire of which was filled with this coma. The diameter of the latter must, therefore, have been more than 18′. The drawing was taken at 21^h. s. t.

Fig. 13.—Oct. 10, 1835.

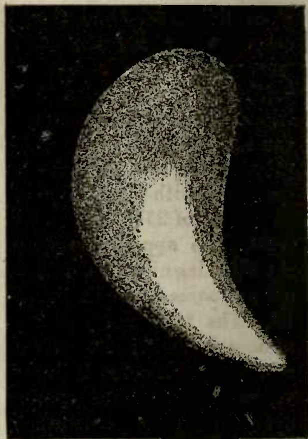


94. The comet is represented in fig. 14 (page 202), on the same scale, as it appeared on the night of the 12th. It appeared at $0^h\ 25^m$ s. t. for a short interval in uncommon splendour, the nucleus and flame, however, alone being visible, as represented in the drawing. The greatest extent of the flame measured 64″·7. Its appearance was most beautiful,

resembling a jet streaming out from the nucleus, like flame from a blow-pipe, or the flame from the discharge of a mortar, attended with the white smoke driven before the wind.

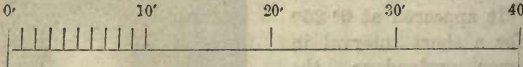
Fig. 14.—Oct. 12, 1835.

Fig. 15.—Oct. 14, 1835.

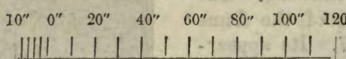


95. Its appearance on the 14th is shown, on the same scale, in fig. 15. The principal flame was now greatly enlarged, extending to the apparent length of 134". Its deflection and curved form were most remarkable.

96. A cloudy sky prevented all observation for 12 days. On the 27th, the comet appeared to the naked eye as bright as a star of the third magnitude, the tail being distinctly visible. The coma surrounding the nucleus appeared as a uniform nebula. The tail was curved and of great length; but, owing to the low altitude at which the observation was taken, it could not be measured. On the 29th, however, the comet was presented under much more favourable conditions, and the drawings, fig. 16 and fig. 17 were made. The former represents the entire comet, including the whole visible extent of the tail, and is drawn to the annexed scale of minutes.

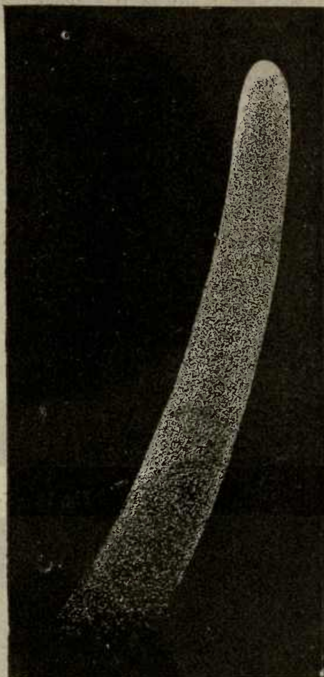


The latter represents the head of the comet only, and is drawn to the annexed scale of seconds.



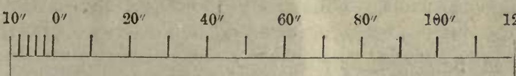
At $20^h\ 30^m$ s. t., the head presented the appearance represented in fig. 17 (page 204). The chief coma was almost exactly circular, and had a diameter of 165″. With a power of 198, the nucleus appeared as in the figure, the diameter being about 1″·25 to 1″·50. The flame issuing from the nucleus, curved back like smoke before the wind, was very conspicuous. The appearance of the formation of the tail as it issues from the nucleus was remarkably developed.

Fig. 16.—Oct. 29, 1835.



97. On the 5th of November the comet appeared as shown in fig. 18 (page 204). This drawing represents the nucleus and flame issuing from it on the scale of seconds given below.

The proper nucleus was found to measure about 2″·3. Two flames were seen issuing from it in nearly opposite directions, and both curved towards the same side. The brighter flame, directed towards the north, was marked by strongly defined edges. The other, directed towards the south, was more feeble and ill-defined.



98. Sir J. Herschel, who also observed this comet himself at the Cape of Good Hope, makes from all these observations the following inferences.

(1.) That the matter of the comet vaporised by the sun's heat escapes in jets, throwing the comet into irregular motion by its reaction, and thus changing its own direction of ejection.

(2.) That this ejection takes place principally from the part presented to the sun.

(3.) That thus ejected it encounters a resistance from some

Fig. 17.—Oct. 29, 1835.

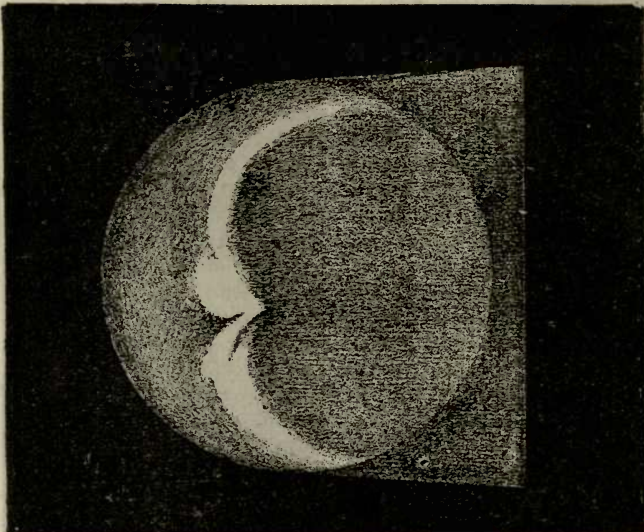


Fig. 18.—Nov. 5, 1835.

unknown force by which it is repulsed in the opposite direction, and so forms the tail.

(4.) That this acts unequally on the cometary matter, which is not all vaporised, and of that which is, a considerable portion is retained, so as to form the head and coma.

(5.) That this force cannot be solar gravitation, being contrary to that in its direction, and very much greater in its intensity, as is manifest by the enormous velocity with which the matter of the tail is driven from the sun.

(6.) That the matter thus repelled to a distance so great from a body whose mass is so small must, to a great extent, escape from the feeble influence of the gravitation of the mass composing the head and coma, and, unless there be some more active agency in operation, a large portion of such vaporised matter must be lost in space, never to reunite with the comet. This would lead to the consequence, that at every passage through its perihelion the comet would lose more and more of its vaporisable constituents, on which the production of the coma and tail depends, so that, at each successive return, the dimensions of these appendages would be less and less, as they have in fact been found to be.

99. On receding from the sun after its perihelion, the comet was observed under very favourable circumstances at the Cape by Sir J. Herschel and Mr. Maclear. It first reappeared there on the 24th of January, under an aspect altogether different from that under which it was seen before its perihelion. It had evidently, as Sir J. Herschel thinks, undergone some great physical change, which had operated an entire transformation upon it.

"Nothing could be more surprising than the total change which had taken place in it since October. . . . A new and unexpected phenomenon had developed itself, quite unique in the history of comets. Within the well-defined head, somewhat eccentrically placed, was a vivid nucleus resembling a miniature comet, with a head and tail of its own, perfectly distinct from and considerably exceeding in intensity the nebulous disc or envelope which I have above called the 'head.' A minute bright point, like a small star, was distinctly perceived within it, but which was never quite so well defined as to give the positive assurance of the existence of a solid sphere, much less could any phase be discerned." *

100. The phenomena and changes which the comet presented from its reappearance on the 24th of January, until its final

* "Cape Observations," p. 397.

disappearance, have been described with great clearness by Mr. Maclear, and illustrated by a beautiful series of drawings by that astronomer and his assistant, Mr. Smith, in a memoir which appeared in the tenth volume of the Transactions of the Royal Astronomical Society, from which we reproduce the series of illustrations given in fig. 19 to fig. 29.

101. On the night of the 24th of January, 1836, the comet appeared, as in fig. 19, visible to the naked eye as a star of the second magnitude. The head was nearly circular, and presented a pretty well-defined planetary disc, encompassed by a coma or halo of delicate gossamer-like brightness. The diameter of the head, without the halo or coma, measured 131″, and with the latter 492″.

102. On the night of the 25th the comet had the appearance represented in fig. 20. The circular form was broken, and the magnitude of the head was increased. Three stars were seen through the coma and one through the head.

103. On the 26th of January the magnitude of the head was further increased, but that of the coma was diminished (fig. 21).

104. On the 27th the comet began to assume a parabolic form, as shown in fig. 22, and the increasing magnitude continued.

105. On the 28th the coma or halo was quite invisible, but the nucleus appeared like a faint small star. The magnitude of the comet continued to increase. The observer fancied he saw the faint outline of a tail (fig. 23).

Fig. 23.—January 28, 1836.

106. On the 30th the form of the comet became decidedly parabolic (fig. 24). The breadth across the head was 702″, being greater than on the 24th in the ratio of 49 to 70, or 7 to 10,

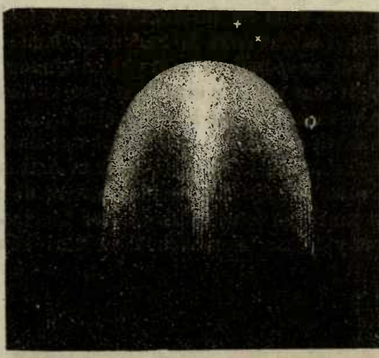
which corresponds to an increase of volume in the ratio of 1 to 3, supposing the form to remain unchanged; but it was estimated

Fig. 24.—January 30, 1836.

that the extension in length gave a superficial increase in the ratio of 35 to 1, which would correspond to a much greater augmentation of volume.

107. On the 1st of February a further increase of magnitude took place, the figure remaining the same (fig. 25).

Fig. 25.—February 1, 1836.



108. On the 7th of February the comet was rendered faint by the effect of moonlight (fig. 26).

109. On the 10th a further increase of volume took place, a star being visible through the body (fig. 27).

110. From the 16th, on which it presented the appearance shown in fig. 28, to the 23rd, when it assumed the appearance shown in fig. 29, the magnitude went on increasing, while the illumination became more and more faint, and this continued until the comet's final disappearance; the outline, after a short time, became so faint as to be lost in the surrounding darkness, leaving a bland nebulous blotch with a bright centre enveloping the nucleus.

111. According to Mr. Hind, the number of comets which have appeared since the birth of Christ in each successive century is as follows: first century, 22; second, 23; third, 44; fourth, 27; fifth, 16; sixth, 25; seventh, 22; eighth, 16; ninth, 42; tenth, 26; eleventh, 36; twelfth, 26; thirteenth, 26; fourteenth, 29; fifteenth, 27; sixteenth, 31; seventeenth, 25; eighteenth, 64; nineteenth (first half), 80. Total, 607.

112. Since comets are visible only near their perihelia, when their velocity is greatest, the duration of their visibility at any single perihelion passage is generally short. The longest appearance on record is that of the great comet of 1811 (No. 8, Table VI., "Hand-Book of Astronomy," chap. xviii.), which continued to be visible for 510 days. The comet of 1825 (No. 2, Table VI. "Hand-Book of Astronomy," chap. xviii.) was visible for twelve months, and others which appeared since have been seen for eight months. In general, however, these bodies do not continue to be seen for more than two or three months.

113. Considering the vast number of comets which have passed through the system, such an incident as the collision of one of them with a planet might seem no very improbable contingency. Lexell's comet was supposed to have passed among the satellites of Jupiter; and, if that was the case, it is certain that the motions of these bodies were not in the least affected by it. The nearest approach to the earth ever made by a comet was that of the comet of 1684 (No. 55, Table VIII., "Hand-Book of Astronomy," chap. xviii.), which came within 216 semidiameters of the earth, a distance not so much as four times that of the moon. We are not aware of any nearer approach than this being certainly ascertained.

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